JOURNAL
OF THE
WASHINGTON ACADEMY OF SCIENCES

VOLUME 35 MAY 15, 1945 No. 5

GEODESY.—*The utility of geodetic control surveys.*[1]

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Geodetic surveys are surveys employed over areas of large extent for which the curvature of the earth must be taken into consideration. Since the curvature depends on the size and shape of the earth, every geodetic survey of necessity is based on some spheroid of reference that has been adopted for that particular part of the earth's surface.

FIGURE OF THE EARTH

The determination of the size and shape of the earth has engaged the attention of many of the leading thinkers of the centuries, but it was not until the early nineteenth century that the problem may be said to have been solved sufficiently to meet most practical problems in surveying and engineering. Extensive investigations since that time have resulted in a number of determinations, succeeding ones generally having the advantage of being based upon more widely distributed data. The exhaustive work of Hayford published in 1910 undoubtedly most nearly represents the true dimensions of the earth so far determined. The accuracy of this work is evidenced by the fact that in 1924 the International Union of Geodesy and Geophysics recommended the International Ellipsoid (the Hayford Ellipsoid with slight modification) for use by all countries that were in a position to adopt it.

Yet we find several different spheroids in use over the world today. For practical purposes and within certain bounds these are undoubtedly adequate. But complications arise in regions such as Europe where owing to different spheroids the problem of determining the relation between coordinates at the boundaries of the countries involved is most serious. In North America the Clarke spheroid of 1866 had been adopted by Canada, Mexico, and the United States before the International Ellipsoid was recommended by the International Union of Geodesy and Geophysics in 1924. To change would be prohibitive because of the great amount of surveys already accomplished.

Great progress has been made in the United States and Alaska during the past 15 years in the extension of arcs of triangulation into new areas. These with the work completed in other parts of the world will afford an excellent opportunity for further research at the first opportunity following the war. While formerly the problem of greatest geodetic importance was the determination of the figure of the earth, now we are more concerned with the practical uses of geodetic surveys as engineering and suveying tools. Obviously the value of any tool depends largely upon its availability.

The triangulation network in the United States today has at least approached the condition where one may readily realize the adaptation of the data to its manifold uses in our economic and industrial existence. Fortunately we have lost little by obsolescence. The basic framework started by Hassler in 1816 conforms well to the demanding requirements of today although accomplished with instruments and equipment that would now be considered crude. This is tribute to Hassler's vision in preparing the groundwork for geodetic operations in this country. It was in 1927, over 100

[1] Address of the Retiring President of the Washington Academy of Sciences delivered at the 331st meeting of the Academy on February 15, 1945. Received February 21, 1945.

years from the beginning, before the triangulation had assumed the proportions of a basic framework susceptible of adjustment into a rigid whole. The increased interest in the use of geodetic control is significantly illustrated by the fact that of the more than 100,000 triangulation stations in the United States today, nearly three-fourths of them have been established in the past 15 years. This condition also applies roughly to other geodetic operations.

PRACTICAL USE

Everyone realizes the vast demands for surveying and mapping created by war. This condition was experienced also in World War I and contributed materially to the increased activity in all classes of mapping in this country in the interval leading up to our entry into World War II. Since then the needs have been unprecedented, and all regular Federal mapping agencies have cooperated with the military departments in meeting the requirements for surveys and maps. It must be recognized that under such conditions the compilation of many types of maps, as for example, aeronautical charts, had to be accomplished as would best meet the emergency and could not wait for the completion of geodetic control. Otherwise extensive use has been made of geodetic surveys in order to maintain complete coordination not only for mapping in this country and Alaska but also in various defense installations at coast and island bases and in the solution of various fire-control problems.

We are here principally concerned with their usefulness as required in our peacetime pursuits. Very briefly, the most essential applications are:

1. For all general surveys of large areas, such as for large-scale mapping, flood control, reclamation, forest inventory or where coordination and permanence of location must be had at the same time.

2. Settlement of boundaries. The use of geodetic control in the referencing of property boundary surveys, although nothing new, is only beginning. When stations become available within reasonable reach of the local surveyor without too much cost to his client, every property owner will desire to reference his surveys to existing monuments that are everlasting and thus insure the retracement of his property boundary lines by competent surveyors at any future time. Such safeguards will result in savings of great sums of money now spent annually in litigation of such matters.

3. Surveys required in city planning. Recently there has been a continually increasing use of precision geodetic surveys for city planning as needed to obtain overall accuracy of the many surveying projects which with time are liable to become rather heterogeneous in metropolitan regions. Several of our large cities now have such surveys and others are anxious to obtain them.

4. Surveys to determine crustal movement, such as that caused by earthquakes, the lowering of ground water level, or in the study of settlement problems such as that caused by the water load at Lake Mead just above Boulder Dam. Here a network of leveling was first accomplished in 1935 before the lake had started filling and the second in 1940, five years later when the water had reached a reasonable height. The results so far show that some changes have taken place, but it is probable that the full effect of the water load will not be evidenced for some years. It is therefore anticipated that levels may be run over the network at suitable intervals to determine further settlement with the passage of time. Precision horizontal angle observations also were made on the marked points on the downstream race of the dam and in the construction on either side of the stream for the purpose of studying problems of structural movement.

5. Precision measurement of base lines or distances as, for example, the measurement of the Pasadena Base and the triangulation between this base and two stations on the mountains between which Michelson made his experiments in determining the velocity of light.

6. For special horizontal alignment and in precise leveling such as that required in the work of the David Taylor Model Basin at Carderock, Md.

7. For the determination of great circle distances between airports which are being used extensively by aviation authorities in

scheduling uniform tariffs for passenger and freight service in this country and in many other parts of the world.

Clearly one function of geodetic control surveys is that of coordination—that is, in making ties to other acceptable control surveys and adjusting them to the national net, thus making them available for general use. Such work forms a very important and valuable addition to the national net.

It is to the interest of all that stations be located where they are least likely to be molested or destroyed and also where they will not interfere with probable improvement or construction. The total cost and value of control surveys at any time are represented by existing stations and bench marks and every effort is made to establish permanent marks easily recoverable.

With some 25,000 monumented triangulation stations and more than 225,000 bench marks, the job of maintenance alone assumes considerable magnitude. Scores of stations and bench marks are lost every year. The problem of maintenance is to keep the loss as low as possible by having lost marks replaced by our field parties and by enlisting the cooperative assistance of a large number of engineers and surveyors engaged in both public and private work. Such people are very public-spirited and generally are pleased to do the work free, since Uncle Sam, prodigal in many ways, has no money for this.

Some have questioned the need for high accuracy in the geodetic control when many of its important uses can be served as well with less accurate work. For many problems such as obtaining a basic framework and for property boundary surveys, the work of high precision is absolutely essential and it is important to bear in mind that one job well done, and at only slightly more cost than less accurate work, serves all purposes equally well indefinitely.

In re-triangulation and re-leveling to determine earth movement resulting from seismic disturbance or in the relocation of lost stations one comes at once to the very heart of the question of accuracy. With what accuracy were those stations or bench marks located or replaced? The answer must be obtained from an analysis of the several actors affecting the accuracy of the final data which may be classified under the following general items:

1. Quality of instrument.
2. Observational procedure.
3. Refraction.
4. Phase and eccentricity.

INSTRUMENTS

Many excellent theodolites suitable for present-day precise triangulation are manufactured (or were before the war) by a number of instrument makers in the United States and in Europe. The horizontal circles of these theodolites vary in diameter from 5 to 9 inches and can be read with micrometer attachment to single seconds, sometimes to tenths of seconds. Most such instruments are small and compact and weigh only 15 to 28 pounds without carrying case and are easily transported from station to station even when backpacking is necessary.

Naturally, for precision triangulation it is most important that the instrument circle be of proved accuracy. This must be obtained from tests simulating field conditions as far as practicable except as regards refraction. This is best accomplished in a testing room where permanent collimators at 15 to 25 feet from the instrument take the place of distant stations as observed in the field. Tests are made on all new instruments before they are sent to the field and whenever they are returned for overhaul. The latest circle tests show that the maximum probable graduation errors are not in excess of 1.5 seconds and, since observations are distributed over the entire circle, graduation errors have little effect on the results.

OBSERVATIONAL PROCEDURE

Observing procedure has been developed with the view of eliminating instrumental and personal errors insofar as practicable. The observations are made from 16 positions of the circle. For every direction taken with the telescope in the direct position there is one with the telescope in the reverse position. A horizontal angle is obtained from the mean value of a minimum of 32 pointings of the telescope on each station for which there are 128 micrometer readings.

REFRACTION

Without question lateral refraction is the greatest source of trouble in triangulation. It is a potential danger constantly to be guarded against. Experience shows that it is nearly always present when there is much cooling of the ground, but the amount is variable and unpredictable. It has been found particularly bad at night when cold winds blow over dry hot ground or surface rocks that are giving off the heat absorbed from the sun during the day. The slope and vegetation of the terrain and its nearness to the ray greatly affect the bending. Some observers claim to have experienced as much as 15 seconds horizontal refraction under severe conditions. However, the greatest amount experienced under normal conditions of observations and proved by triangle closure of which we have knowledge was between 7 and 8 seconds. Stations and towers must be so located that rays to other objects will not pass close to houses, tree trunks, or tripod legs. Triangulation in cities quite frequently is difficult because of refraction caused by heat and smoke from chimneys. There are certain phenomena that an experienced observer recognizes as indicating the existence of a disturbed condition. Otherwise there is not much to be done about it except to go ahead and observe when other conditions permit.

In observing vertical angles it is well known that the refraction is rather variable especially near sunrise or sunset, and sometimes it is very erratic. Furthermore, owing to the extreme condition of cloudiness during some seasons, or in some regions such as Alaska, it becomes necessary to make the observations whenever they may be obtained, generally at night. For these reasons trigonometric leveling can not be expected to produce precision results and such observations are made only where elevations cannot be determined by other practicable means.

Spirit leveling is also seriously affected by vertical refraction, and therefore every effort is made to eliminate or reduce it to a minimum. The program is planned to vary the conditions under which the backward and forward lines are run with reference to the direction of wind and sun, and in all probability the effect of refraction is eliminated on level ground. In leveling up steep grades where the upgrade sight is always near the ground while the downgrade sight is far from it, there is a differential in the amount of refraction which is extremely difficult to control.

PHASE AND ECCENTRICITY

Phase is particularly troublesome in daylight observations when the appearance and shape of objects are altered owing to the change in the direction of the sunlight on them. Observations for first and second-order triangulation are practically all made on electric signal lamps at night and this procedure largely overcomes the problem of phase. Furthermore, since each lightkeeper is required to point the center of the beam of his lamp to the observer, there is no eccentricity except what might be due to the imperfection of the reflector. Observations made at night are more accurate than those made during the daytime because the atmospheric conditions are better generally and there is less difficulty from lateral refraction. As a rule daylight observations are made only on chimneys, water tanks, cupolas and other identifiable objects. These probably are affected to some extent by phase though precautions are taken to guard against it insofar as practical. Such points, moreover, are used for photogrammetric and other control and are not considered as first-order.

Another problem is that of eccentricity. All horizontal angle observations should be made with the instrument and the lamps, heliotropes or other signals centered perfectly over the stations. This is not as simple as it may seem and frequently becomes of critical importance. The shorter the lines the greater the care required in centering the instrument and the objects sighted upon.

TRIANGLE CLOSURE

On first-order triangulation it is required that the average triangle closure shall not exceed 1 second and that no closure shall exceed 3 seconds. A further

check is that the logarithm of the length of the sides of the triangulation as determined by the different triangles through which the computations are carried shall not exceed three times the difference for 1″ of the logarithm for the smallest angle entering the computation.

LIMIT OF ERROR

The errors that may be caused by instrumental or observational imperfections are controlled within very narrow limits. Divergences from the true values evidently are caused by erratic and unusual conditions and do not occur frequently. Where they do occur the safeguard against them is the maximum allowable triangle closure of 3″, which requires that the faulty observations must be repeated until acceptable results are obtained. Experience shows that 10 percent of the stations have to be reoccupied in obtaining first-order results. The maximum discrepancy that can be caused by the total allowable error on one or more directions in a single closed figure of triangulation (usually a quadrilateral) depends largely on the strength of the figure.

The accuracy of first-order triangulation can best be estimated by comparing the measured lengths of base lines with the lengths as determined by computation through the triangulation from the preceding base and by triangulation loop closures. It was found from a recent test involving 32 base lines that the average closure on bases is of the order of 1 part in 54,500. The specifications require an accuracy of 1 part in 25,000 which is the largest acceptable limit.

Only a very brief discussion of the leveling net will be given. The net consists of more than 225,000 bench marks distributed over more than 300,000 miles of lines in the United States.

The specifications for first-order leveling are that the forward and backward runnings of a section shall not differ by more than $4 \text{ mm } \sqrt{K}$ where K is the length of the section in kilometers. An indication of the accuracy is the fact that the average correction applied in distributing the adjusted loop closures is of the order of 0.1 mm per kilometer or 1 cm in 62 miles.

GRAVITY DETERMINATIONS

Gravity observations properly distributed over the surface of the earth form an excellent means of determining the shape of the earth and were used very extensively for that purpose until the beginning of the war when operations in many countries including the United States were suspended. Differences between actual and theoretical gravity (anomalies) are sometimes quite large and are presumed to be due to lack of isostatic adjustment or to buried structure or perhaps to both. Such buried structure may consist of salt domes or buried granite ridges, both of which are associated with the location of petroleum. Gravity observations made to determine the shape of the earth and to establish the base stations used in geophysical exploration are made with a pendulum apparatus of which special types have been developed for work both on land and on the sea. Gravity observations used in search of oil and minerals have generally been made with gravimeters of which there are also several types, all of comparatively recent development. These instruments are extremely accurate for local surveys, and observations at a station can be made in only a few minutes. Furthermore, they are easily transported and at small cost.

NORTH AMERICAN DATUM

In 1913 the governments of Canada, Mexico and the United States jointly adopted a common datum of reference for their horizontal control surveys, which was designated the North American Datum. This action was taken in the interest of efficiency and economy to avoid double coordinates at the boundaries and to establish uniformity and continuity in mapping procedure. Representatives of some of the countries of Central America have also expressed a desire to coordinate the geodetic surveys in their countries on the North American Datum. Thus it would appear that the North American Datum

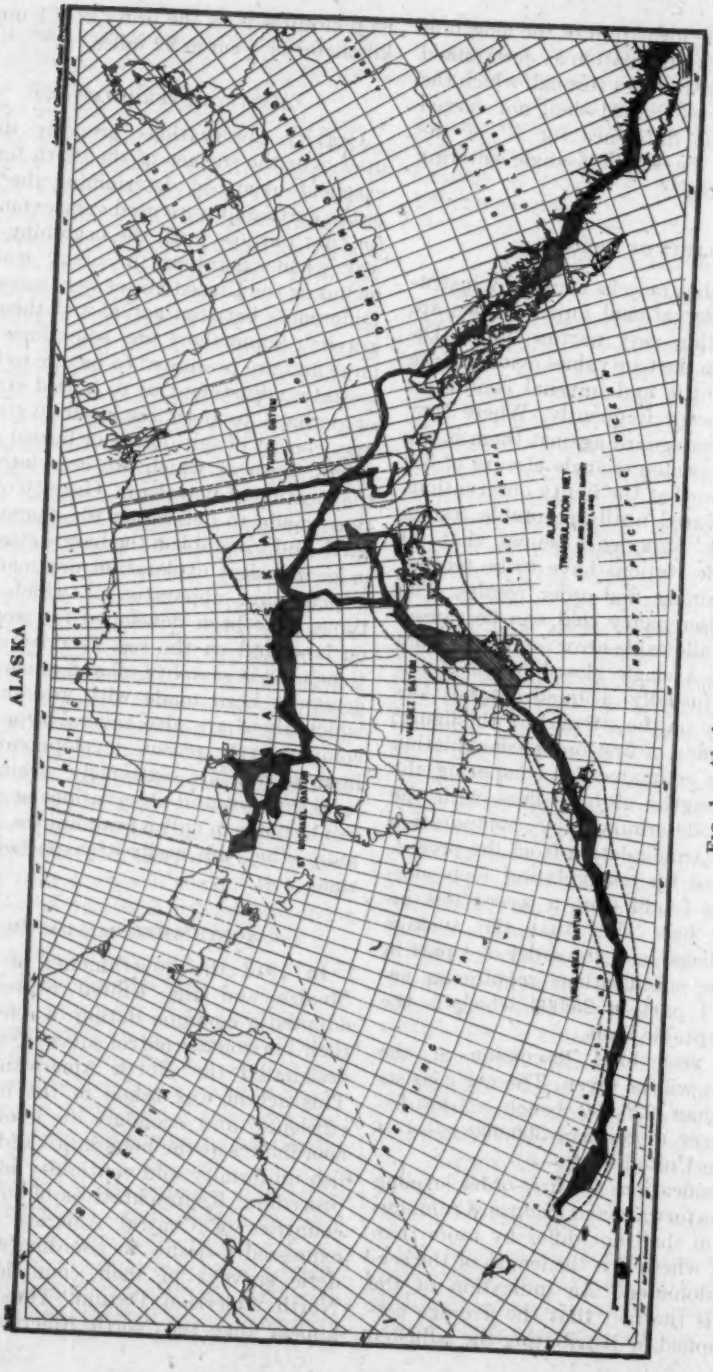

FIG. 1.—Alaska triangulation net.

may eventually be expected to extend all over North America and to a connection to the geodetic work of South America somewhere on the Isthmus of Panama.

At the request of the War Department and through the cooperation of Canada it has been possible during the past four years to extend the North American datum into the interior of Alaska. Through this work what previously were four independent geodetic datums (Yukon datum, Valdez datum, Unalaska datum and St. Michael datum) are now referred to the North American Datum. The triangulation scheme to Alaska follows the Alaska Military Highway, and in fact, was carried on while the road was under construction (see Fig. 1). This single line of communications and travel along the axis of the scheme probably reduced the cost to one-fifth of what it otherwise would have been. Air transportation was required for about 75 percent of all field operations on the work west of Fairbanks. This was accomplished by the use of light float planes of from 200 to 800 pounds capacity which could be landed on small lakes and streams near the stations. By reason of this work there is now a continuous arc of first-order triangulation from Bering Strait, which separates Alaska from Siberia, through Alaska, Yukon, southeast Alaska, British Columbia, the United States, and Mexico to southern Mexico, a distance of approximately 5,400 miles.

WESTERN HEMISPHERE

The events of the past three years have emphasized among other things the need of international cooperation in mapping. Prior to 1941 no concerted action had been taken by countries in the Western Hemisphere in regard to geodetic surveying or in fact concerning any phase of mapping. The situation was very suddenly changed when the war spread to the Western Hemisphere bringing an unprecedented demand for all classes of maps of world coverage, particularly for aeronautical charts.

Another potent factor toward accelerating surveying and mapping in the Western Hemisphere has been the two recent Pan American Consultations on the various branches of cartography, the first of which was held in Washington in October 1943 and the second in Rio de Janeiro August 14 to September 2, 1944. The following is quoted from a report in the January 1945 issue of the Bulletin of the Pan American Union by Robert H. Randall, United States Member and Chairman of the Committee on Cartography, Pan American Institute of Geography and History:

> The American Geographical Society acted as host for the United States, and the Commission on Cartography of the Pan American Institute of Geography and History acted as joint sponsor, and organized the Consultation. Broad lines for the program of mapping improvement in the hemisphere were drawn. The First Consultation was attended by technical representatives from the countries of North and South America. In the Second, all of the American nations with the exception of El Salvador, Haiti and Nicaragua, were represented. The Brazilian Government joined the Pan American Institute in sponsoring the Second Consultation and the general program outlined in the First Consultation was further refined, and specific recommendations as to immediate and future procedure were made.
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> The nations of the American Hemisphere have, for the most part, always been conscious of the need for more and better map information. The need for maps of certain classes, notably aeronautical charts, has been critical since the beginning of the Second World War. For while the excellent maps compiled by the American Geographical Society were fortunately complete and available for most of Latin America at the beginning of the war, the need of charts for air transport and related purposes made it necessary to fly over and photograph large portions of the Southern Hemisphere. Further, aeronautical charts prepared in some South American localities by the Germans before the war were found to be not only inaccurate but apparently purposely so.
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> The lack of map information in some areas, and the unreliability of the information in others, called for a tremendous effort in the production of aeronautical charts. The job was undertaken by the United States Air Forces, in cooperation with the other American nations concerned. The series of aeronautical charts which resulted was prepared in a remarkably short period of time. Furthermore, the charts are of such a high standard that they constitute a milestone in the geographic progress not only of the Hemisphere but of the entire planet.

Interest in such matters has been further accelerated by the State Department's program of cultural relations in cooperation with the American Republics in which several Federal departments and agencies are actively cooperating. The Coast and Geodetic Survey has five small projects, three of which consist of the intern training type, which provide for representatives from certain countries to visit the United States and observe our methods of geodetic and hydrographic surveying and of map and chart reproduction. The present program provides for training 21 students each year.

The principal of triangulation, that is, the ability to determine the distance and direction to far distant and inaccessible points without actually going anywhere near them, probably will always be one of fascinating interest. The discovery of this geometric law, although certainly more than 2,000 years old, must have been as epochal in its time as the discovery of electricity or radio in ours. Of this, President Woodrow Wilson in a public address in 1916 said: "I have wished, particularly since I entered public life, that there was some moral process parallel to the process of triangulation so that the whereabouts, intellectually and spiritually of some persons, could be discovered with more particularity."

PHYSICS.—*Faster than sound.*[1] THEODORE VON KÁRMÁN, California Institute of Technology. (Communicated by HUGH L. DRYDEN.)

The modern mathematical theory of flight as worked out in the past three decades is based on the assumption that the air can be considered as an incompressible fluid. At first thought this assumption may appear rather paradoxical, since, while water is considered as the typical example of an almost incompressible fluid, air is justly regarded as the typical example of compressible fluid medium. Nevertheless, the theory of incompressible fluids furnished, for example, good approximations of the forces acting on airplane wings, provided the flight speeds of airplanes are small in comparison with the velocity of sound. The entrance of the velocity of sound into the problem has nothing or very little to do with acoustic phenomena. The term velocity of sound stands for the velocity of propagation of small pressure changes in the fluid medium. If this velocity of propagation is large in comparison with the velocities involved in the fluid motion concerned, it can be considered as being of infinite magnitude as well. However, infinite velocity of sound is the characteristic feature of an incompressible fluid. This explains the success of the classical hydrodynamical theory of incompressible fluids in aeronautics. However, as the airplane became speedier, the deviations from the results predicted by the theory of incompressible fluids became larger and larger. As the flight velocity surpassed approximately two-thirds the velocity of sound, it became evident that the discrepancy between the actual phenomena and the simple theory can no longer be removed by small corrections. The so-called "compressibility effects" became a plague and headache of the airplane designers who were used to thinking in terms of low speed aerodynamics. It appeared necessary to consider the air as compressible and to work out the theory of wings, propellers, and other devices based upon the laws of the dynamics of compressible fluids. This reformulation of aerodynamic theory became a necessity as in our ambitious and air-minded age the speed of airplanes is being pushed up to and perhaps beyond the velocity of sound. The requirements of modern warfare have further accelerated this process.

To be sure, the science of ballistics has dealt for a long time with supersonic flow

[1] The thirteenth Joseph Henry Lecture of the Philosophical Society of Washington, delivered at the 1234th meeting of the Society on April 29, 1944. Received January 27, 1945.

phenomena. However, the speed of projectiles is in general several times the velocity of sound. The mathematical theory for such a case is relatively simple. The great difficulties—both for the mathematical calculations and for the physical understanding—appear in the range which recently was denoted as "transsonic." This is the range of velocities just below and just beyond the velocity of sound, where the air flow pattern contains both regions of subsonic flow and of supersonic flow.

Let us consider for example the law for the resistance of a body moving in a fluid medium. This law can be expressed as a functional relation between certain dimensionless combinations of the velocity of motion, the size of the body, and the physical properties of the medium. Such a dimensionless combination is, for example, the drag force D divided by an appropriately chosen sectional area S of the body, the density ρ of the medium and the half of the square of the velocity v. It is evident that $\rho v^2/2$ has the dimension of pressure; as a matter of fact, it is equal to the stagnation pressure of an incompressible fluid moving with the velocity v and having a density equal to ρ. Hence, the surface S multiplied by $\rho v^2/2$ has the dimension of a force. The dimensionless combination $D/[S(\rho v^2/2)]$ is called the drag coefficient and is a function of two other dimensionless combinations which are known as the Reynolds number and the Mach number. The Reynolds number expresses the relative influence of the inertial and the frictional forces. The Mach number expresses the influence of compressibility. It is defined as the ratio between the velocity of a motion or a flow and the velocity of sound. Now, experience and theory show that as long as the "Mach number of the motion," i.e., the ratio between the velocity of motion of the body and the velocity of sound in the medium, is small in comparison with unity it has no significant influence on the drag. If the Mach number reaches values comparable with unity, the compressibility of the air has very large influence on the drag and other aerodynamic characteristics of the body. To be sure, the Mach number remains the governing factor over the entire supersonic range; however, if the velocity of the moving body is considerably higher than the velocity of sound, aerodynamic coefficients change with the Mach number at a moderate rate and the flow pattern retains its general character. In the range of velocities slightly lower and slightly higher than the velocity of sound radical changes in the flow pattern take place and the phenomena are much more complex than in the pure subsonic and pure supersonic ranges, essentially because regions of subsonic and supersonic flow are coexistent. This speed range is designated as the transsonic range.

The magnitude of the velocity of sound in a fluid medium is determined by the equation $c^2 = dp/d\rho$ where p is the pressure and ρ is the density of the medium. The pressure p is considered in this equation as a function of the density ρ. It is assumed that the change of density with change of pressure is fairly well approximated by the relation corresponding to adiabatic change. The easiest way to obtain the expression for the velocity of sound is based on the consideration of the propagation of a small pressure change from the viewpoint of an observer who moves with the propagating front. For such an observer the motion of the fluid appears as stationary flow; the fluid appears moving through the front with the velocity of sound in a direction opposite to the direction of propagation. Let us denote the pressure increment through the front by dp and the corresponding increment of the density ρ by $d\rho$ and the velocity of the fluid moving against the front by c; then according to Bernoulli's equation for stationary flow the velocity c changes as the fluid passes through the front by the amount

$$dc = -\frac{1}{c}\frac{dp}{\rho}. \qquad (1)$$

Now, since $c\rho$ is the mass of fluid passing through the front in unit time, the continuity of matter requires that the product of density and velocity remains constant. Consequently, $c\rho = (c+dc)(\rho+d\rho)$ or $cd\rho + \rho dc = 0$ and therefore

$$dc = -\frac{c\,d\rho}{\rho}. \qquad (2)$$

Combining the two equations we obtain $c^2 = dp/d\rho$. Hence, the velocity of propagation of an infinitesimally small pressure increment dp is equal to $\sqrt{dp/d\rho}$ as indicated above. Substituting the value of the derivative $dp/d\rho$ from the equation of the adiabatic change $p = \text{const}\ \rho^\gamma$, where γ is the ratio of the specific heats of the medium at constant pressure and constant volume, we have $c^2 = \gamma p/\rho$.

Newton gave an expression for the velocity of sound in air, which in modern language amounts to the formula $c^2 = dp/d\rho$. In his calculation of the value of c, he used the relation $p = \text{const.}\ \rho$ (isothermal law). We can not blame him for this, since in his time the equivalence of heat and work was not yet recognized. However, he noticed that his value was too small in comparison with the measured value, which was obtained by observation of gun shots. He tried to apply certain corrections in order to reconcile theory and experiments. The real reason for the discrepancy was found almost a hundred years later by Laplace.

With $c^2 = \gamma p/\rho$, the square of the Mach number of a fluid flow or a moving body can be expressed by the following combination of velocity, pressure, and density:

$$M^2 = \frac{v^2}{c^2} = \frac{\rho v^2}{\gamma p}. \qquad (3)$$

Perhaps the two most important basic problems of fluid mechanics applied to engineering are the flow of a fluid in a conduit and the motion of a solid body in a fluid medium at rest. In both cases we find certain interesting facts in the transsonic region, i.e., when the velocity of the fluid in the conduit changes from subsonic to supersonic or the velocity of the moving body passes through the velocity of sound. We will see that these peculiar phenomena in the two cases are interconnected, and as a matter of fact, engineering ingenuity was necessary to obtain supersonic flow in a conduit, and engineering ingenuity will be necessary to design airplanes flying with a speed greater than the velocity of sound. However, the difficulty in the first case was surmounted when engineers recognized the fundamental laws of supersonic flow, whereas the difficulties to be surmounted for transsonic flying require the solution of intrinsically difficult problems in power plants and airplane design. Let us consider first the problem of flow through a conduit.

If we mount a so-called simple rounded orifice on the wall of a pressure vessel and observe the efflux of a gas, we find the following results: As long as the pressure difference between the inside and outside pressure is small in comparison to the inside pressure, the velocity of outflow obeys approximately Torricelli's law. It is equal to $\sqrt{2gh}$, where h is the pressure height. The rate of flow is equal to the cross-sectional area of the orifice multiplied by this velocity. If the pressure difference is increasing, the quantity of outflow gradually lags behind the value given by this rule. At a certain value of the ratio between inside and outside pressure the quantity of efflux reaches a maximum. We call this pressure ratio the *critical pressure ratio*. Its value is given by the equation

$$\frac{p_e}{p} = \left(\frac{\gamma+1}{2}\right)^{\gamma/\gamma-1}.$$

If the outside pressure is lowered further, while the nozzle pressure is kept constant, the velocity and the rate of efflux remain unchanged. A simple calculation shows that the velocity in the orifice is equal to the velocity of sound corresponding to the pressure and density prevailing in the orifice. This experience led quite a few engineers of the nineteenth century to the conclusion that the velocity of flow from a pressure vessel to the outside atmosphere cannot be greater than the velocity of sound.[2] It is known that the Swedish engi-

[2] St. Venant and Wantzel (1839) derived the correct relation between velocity and pressure in a compressible fluid. They determined the maximum value of the efflux, but did not give a full picture of what happens when the pressure ratio is larger than critical. Since the application of their formula to the pressure ratio exceeding the critical value would indicate a decrease of the efflux with increasing pressure ratio and zero efflux into vacuum, they made the hypothesis that when the ratio between inside and outside pressure is supercritical, the pressure on the orifice is not

neer Carl Gustaf Patrick DeLaval showed by practical experiments that this is not true. If we employ a converging-diverging nozzle, much higher velocities can be obtained. The maximum velocity corresponds to outflow into vacuum and is equal to

$$V_{max} = \sqrt{\frac{2\gamma}{\gamma-1}\frac{p_c}{\rho_c}}$$

where p_c and ρ_c are the pressure and density in the pressure chamber. This value is for air about 2.235 times larger than the velocity of sound corresponding to the pressure and density prevailing in the vessel, and 2.450 times larger than the velocity of sound prevailing at the "throat" of the nozzle. The "local Mach number" of the flow itself, i.e., the ratio between the velocity of flow and the velocity of sound prevailing at the same location, increases to infinity since the velocity of sound in vacuum is theoretically zero.

The reason for the necessity of a converging-diverging nozzle becomes evident if we combine Bernoulli's equation for adiabatic frictionless flow and the equation of continuity. Then it appears that the product of the velocity and density reaches a maximum value at a certain value of the pressure. According to the continuity equation, the product of cross-sectional area, velocity and density is constant along the nozzle. Consequently the maximum value of density times velocity corresponds to a minimum value of the cross section. The maximum value of $v\rho$ is given by the equation $d(v\rho)=0$, or

$$\frac{dv}{v}+\frac{d\rho}{\rho}=0. \qquad (4)$$

If we combine this equation with Bernoulli's equation written in the form $dp/\rho=-vdv$ and eliminate dv we obtain $v^2=dp/d\rho$, i.e., the square of the velocity in the minimum cross section, in the so-called "throat," is equal to $dp/d\rho$, i.e., to the square of the local velocity of sound. Whether the velocity be larger or smaller than the velocity in the throat, the same amount of mass flow requires a larger cross-sectional area than the throat area.

Table 1 shows the comparison between the equations for incompressible and compressible fluids. Fig. 1 illustrates the relation between cross section and velocity for an incompressible fluid (curve a) and for a compressible fluid expanding adiabatically (curve b). The equation for the cross section S can be written in the form:

$$\frac{dS}{S}=\frac{dv}{v}(M^2-1)$$

where $M=v/c$ is the local Mach number. It is seen that dS is positive for positive

TABLE 1

	Incompressible fluid	Compressible fluid
Continuity	$Sv=$Const.	$S\rho v=$Const.
Differential form	$dS/S+dv/v=0$	$dS/S+d\rho/\rho+dv/v=0$
Bernoulli's equation	$dp/\rho+vdv=0$	

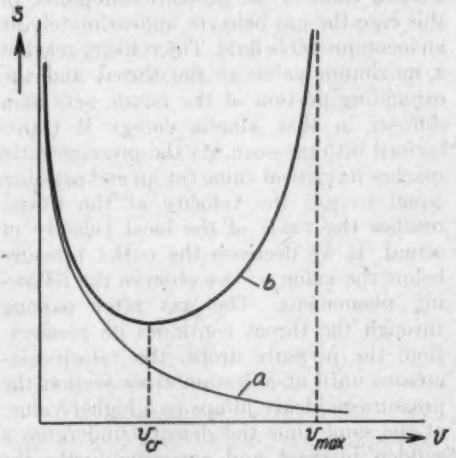

FIG. 1.—Relation between cross section and velocity for an incompressible fluid (curve a) and for a compressible fluid expanding adiabatically (curve b).

equal to the outside pressure. This hypothesis was discussed pro and con in the engineering literature of the following decades. It seems that Osborne Reynolds (1886) was the first author who completed the theory both for the case of a simple orifice and that of the convergent-divergent nozzle.

values of dv when $M>1$, and negative when $M<1$.

We do not want to discuss here the application of the mechanics of compressible fluids to the design of machines like compressors and steam and gas turbines. However, it is necessary to point out an essential difference in the behavior of a converging-diverging nozzle in the subsonic and supersonic range. The nozzle shown in Fig. 2 is designed for a certain pressure ratio p_e/p_a, which is larger than the critical. If the computed pressures prevail at the inlet and outlet, we obtain a flow with adiabatic expansion of the gas from the pressure p_e to p_a; the flow is supersonic between the throat and the outlet. Let us now consider the behavior of the fluid when the pressure at the outlet is raised, whereas the pressure at the inlet is kept constant. We start with a small value of the pressure difference. In this case the gas behaves approximately as an incompressible fluid. The velocity reaches a maximum value at the throat and the expanding portion of the nozzle acts as a diffuser in that kinetic energy is transformed into pressure. As the pressure ratio reaches its critical value (at an exit pressure equal to p_e') the velocity at the throat reaches the value of the local velocity of sound. If we decrease the outlet pressure below the value p_e', we observe the following phenomena. The gas after passing through the throat continues its acceleration, the pressure drops, the velocity increases until at a certain cross section the pressure suddenly jumps to a higher value; at the same time the density undergoes a sudden increase and correspondingly the velocity decreases. We call this phenomenon a "compression shock." Such a compression shock can occur either inside the nozzle mostly as a "normal shock" or starting from the rim of the outlet section as a so-called oblique shock. Sometimes we observe an oblique shock also inside the nozzle. In such a case the flow separates from the wall so that the main flow occupies the center part of the nozzle and a certain space in the neighborhood of the walls is filled with eddying fluid.

The theory of compression shocks for ideal fluids has been worked out theoretically by several scientists in detail. However, the experimental research shows considerable variance with the simple theory mostly due to the friction at the wall. We know that strictly speaking the velocity of the fluid is zero at a solid surface and increases gradually in the boundary layer until the full value prevailing in the main flow is reached. Consequently, even if the main flow is supersonic, near the wall we always have subsonic flow. This fact alone is sufficient to show why the theory of ideal fluids can not explain all phenomena connected with compression shocks. The experimental research in this field is yet in the early beginning stages. The main conclusion we draw from theory and observations is the different behavior of the fluid in the subsonic and supersonic range as far as flow against increasing pressure is concerned. In subsonic flow, i.e., when the velocity at no place surpasses the velocity of sound, we are able to transform pressure into velocity and retransform velocity into pressure in a continuous manner. To be sure, the retransformation of kinetic energy into pressure involves more loss than the transformation of pressure into kinetic energy, but it occurs without discontinuous change in either pressure or velocity. However, if the velocity once surpassed the velocity of sound, in general we are unable to carry out the retransformation of the kinetic energy into pressure without sudden change and this sudden change involves undesirable transfer of mechanical energy in heat instead of pressure.

The main physical reason for the occurrence of the compression shock is the following: Let us first assume a purely subsonic flow through a converging-diverging nozzle. If we raise the outlet pressure by a small amount, the pressure change propagates upstream with a velocity which is equal to the velocity of sound minus the velocity of flow. The end effect is an adjustment of the pressures and velocities in every cross section to the new pressure ratio. However, if the velocity at the outlet is supersonic, a small pressure rise is unable to travel upstream, since the velocity of the gas is larger than the velocity of pressure propa-

gation. Consequently, the effect of pressure change that is imposed on the periphery of the jet is confined to the downstream portion of the jet, more exactly to the region downstream from a conical surface emanating from the cross section of the orifice. In this case we obtain an oblique shock outside the nozzle. Now it can be shown that a finite pressure rise travels with a higher velocity than the velocity of sound which is, strictly speaking, the velocity of propagation of an infinitesimal pressure change. Consequently, a large pressure rise applied to the outlet is able to intrude upstream into the nozzle. By doing so its intensity and its velocity of propagation decreases until it becomes equal to the velocity of the stream. Thus we obtain a stationary compression shock at some cross section inside the nozzle.

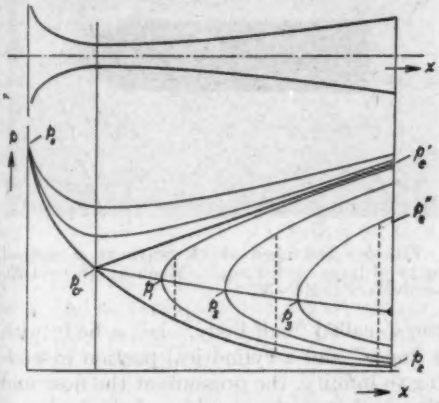

FIG. 2.—Computed pressure distributions in a converging-diverging nozzle for various exit pressures.

Fig. 2 shows computed pressure distributions along the axis of a nozzle for various exit pressures p_e. The limiting value for which subsonic flow occurs is denoted by p_e'. The exit pressure which produces supersonic flow without shock is p_e. The curves ending at values between p_e and p_e' denoted by p_e'' refer to adiabatic change of state after a shock occurred. The curve $p_c p_1 p_2 p_3$ refers to states in which the velocity is equal to the local velocity of sound. If the exit pressure is above the end point of this curve, the shock is inside of the nozzle and the flow beyond the shock is subsonic. If the end pressure is lower the flow is supersonic along the whole nozzle and the applied shock occurs downstream outside of the nozzle.

We can produce compression shock by performing another fundamental experiment, namely, putting an obstacle, for example, an inclined plane or a wedge in the way of the gas moving with supersonic velocity (Fig. 3). If we perform this experiment in a subsonic stream, we obtain the stagnation pressure at the corner and the flow is deflected smoothly to follow the new direction. In the case of supersonic flow the pressure rise caused by the obstacle is unable to propagate indefinitely in the upstream direction. If the angle of deflection is small, we obtain a compression shock starting out from the corner. If the angle of deflection is larger, the pressure rise will travel to a certain distance up stream and we obtain a stationary compression shock at a certain distance up-

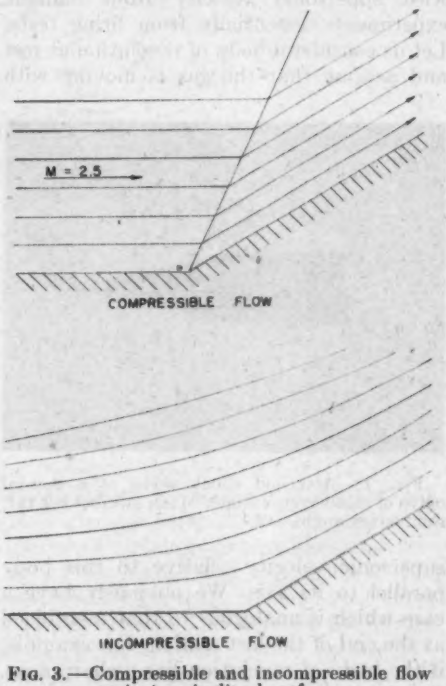

FIG. 3.—Compressible and incompressible flow against an inclined surface.

stream from the corner.[3] Between the compression shock and the wedge in this case the flow is subsonic. These fundamental observations are helpful in the understanding of the phenomena connected with the problem of a body moving in a fluid at rest which we shall consider more conveniently as the problem of flow in an infinitely extended fluid around a solid body.

Considerable experimental material is available about the drag of bodies moving with supersonic velocity from ballistic experiments, essentially from firing tests. Let us consider a body of revolution at rest and assume that the gas is moving with supersonic velocity relative to this body parallel to its axis. We obviously have a case which is analogous to that mentioned at the end of the last section. For example, if the body of revolution has a sharp nose, the fluid moving with supersonic flow is forced to be deflected in the direction of the tangential plane of the ogive. If the angle of deflection is small (Fig. 4), we obtain a compression shock starting from the vertex. If the angle of deflection is large (Fig. 5), we obtain a compression shock in the free air upstream from the body. Such a shock is called a detached shock.

Let us consider the influence of a compression shock on the drag. In the purely subsonic case the drag of a body consists of two parts; the frictional drag and the form drag. The frictional drag is an unavoidable item in any real, i.e., viscous fluid. The form drag can be avoided if we prevent separation, or as we sometimes say, vortex shedding from the body. As a matter of fact, a streamlined body in an ideal incompressible fluid has no drag at all, as was recognized very early by d'Alembert. To be sure, we obtain a pressure rise at the nose equal to the stagnation pressure. However, this pressure rise is balanced by suction at the front part and by pressure at the rear part of the body. In the case of the so-called "half body," i.e., a body with a "nose" and a cylindrical portion extending to infinity, the pressure at the nose and the suction at the shoulder of the body are balanced in a way that the resultant force is zero. The same statement is true for an ideal compressible fluid provided the flow is subsonic everywhere. In the case of the supersonic flow the pressure at the nose is in general smaller than the stagnation pressure, but owing to the compression shock no suction of the shoulder occurs or at least it is reduced to such extent that a considerable form drag results. Fig. 6 shows computed pressure distributions on the nose part of a half body for incompressible flow and for supersonic flows at various Mach numbers. Fig. 7 shows experimental drag curves for a shell with sharp nose, and for several shells with blunt noses,

FIG. 4.—Attached shock wave at a conical ogive of small vertex angle. Mach number = 2.481, semivertex angle = 12.1°.

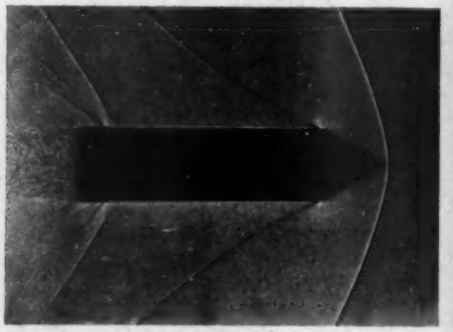

FIG. 5.—Detached shock wave at a conical ogive of large vertex angle. Mach number = 1.25, semivertex angle = 30°.

[3] Strictly speaking, if the "deflector plate" is extended to infinity, the compression wave would travel upstream to infinity; if the length of the deflector is finite, the above statement is correct.

including a sphere. A shell or a sphere has considerable form drag also at low Mach numbers, due essentially to the wake produced by lack of streamlining of the rear end of the body. However, the drag increases rapidly as the velocity of the shell passes through the velocity of sound of the medium. It is seen that this increase starts at a Mach number substantially smaller than unity and the shape of the curve in this transition range which we denoted by the term "transsonic" apparently greatly depends on the form of the nose. The following section deals with this range.

Instead of a shell we shall consider a cylindrical body such as an airplane wing of long span moving through the air at rest. Let the velocity of motion be smaller than the velocity of sound. To an observer moving with the wing the fluid appears to approach the wing with a certain subsonic velocity and is accelerated along the curved boundaries of the wing. Let us assume for the sake of simplicity that the air is not extended indefinitely but is limited by two surfaces parallel to the direction of motion of the wing and at a certain distance from the wing. Obviously both the upper and the lower parts of the flow are analogous to a flow in convergent-divergent nozzles. We have a throat at the upper surface of the wing and a throat at the lower surface.

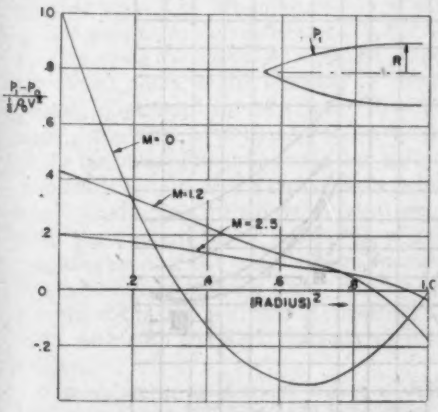

FIG. 6.—Computed pressure distributions on the nose of a half body for incompressible flow ($M=0$) and for supersonic flows at various Mach numbers.

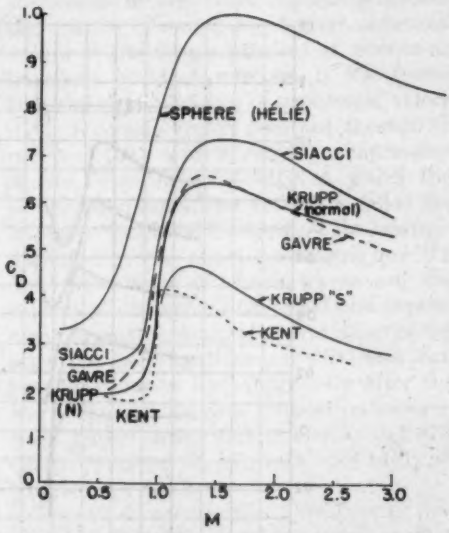

FIG. 7.—Experimental drag curves for a shell with sharp nose (Kent), for several shells with blunt nose, and for a sphere.

Consequently, the velocity of sound may be reached in the throat before the body itself moves with sonic velocity. The flight velocity at which the local velocity reaches the local velocity of sound is sometimes called the "lower critical velocity of the wing." Now in reality the air is not restricted by a solid surface; however, the outer part of the air exerts a certain resistance against deflection by its inertia and the result of this resistance is essentially similar to the effect of a solid surface. Therefore, in the airflow adjoining the airplane surface similar phenomena will occur as are observed in nozzles. We have seen that the flow in the nozzle is characterized by two facts: first, if the velocity of sound is reached in the throat the amount of fluid flowing through the nozzle cannot be increased further. Second, if the downstream pressure is higher than corresponds to the expansion ratio of the nozzle, a compression shock results. Both phenomena can be observed in the case of the wing. The first one causes a substantial decrease of the lifting capacity of the wing; the second one increases its drag.

The amount of lift produced by an airplane wing, is, generally speaking, determined by the difference of pressure between

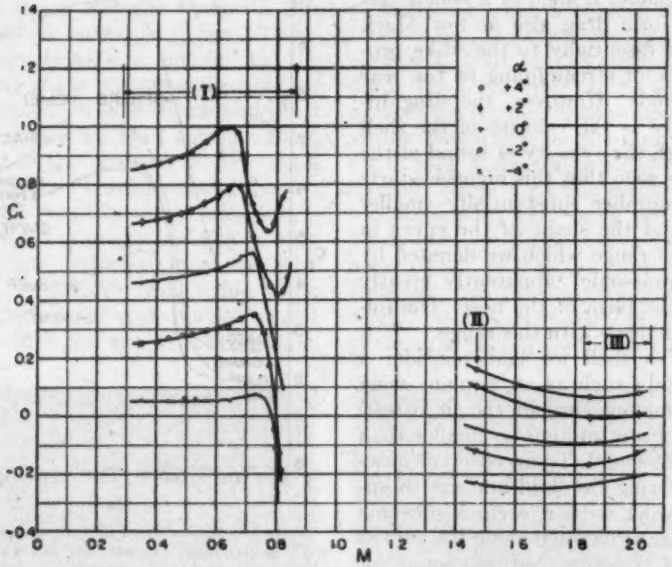

FIG. 8.—Lift coefficients of airfoils as a function of Mach number M and angle of attack α.

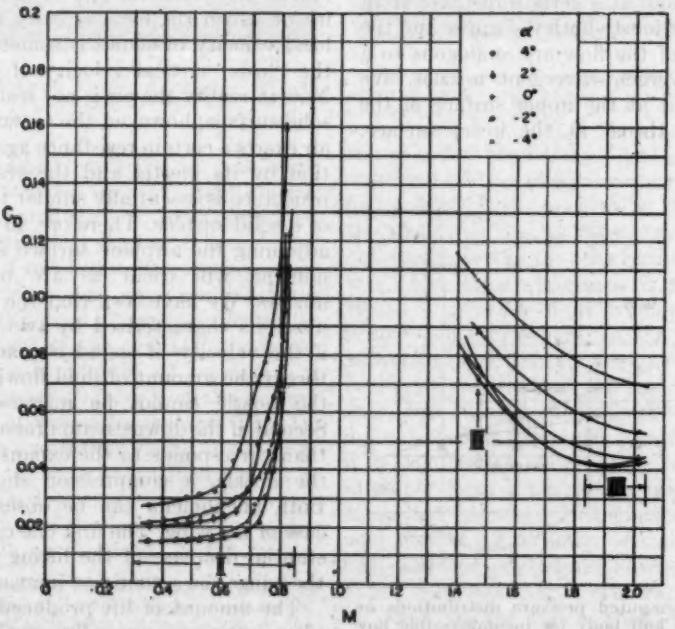

FIG. 9.—Drag coefficients of airfoils as a function of Mach number M and angle of attack α.

the lower and the upper surface. For example, in the case of a cambered wing the air is accelerated along the upper surface to a greater extent than at the lower surface, and therefore at the upper surface a larger suction will be produced than at the lower surface. The difference of the resulting suctions furnishes the lift of the wing. Now it is evident that because of the larger camber of the upper surface the velocity of sound will be reached sooner in the upper than in the lower surface. In other words, what we can call the throat condition will occur earlier at the upper surface. Consequently, even if we further increase the flight velocity of the wing the magnitude of the suction at the upper surface will cease to increase. The lift practically becomes independent of the velocity of flight, whereas in subsonic conditions the lift of an airplane wing increases with the square of the velocity. We call the ratio between the lift per unit area and the dynamic pressure of the corresponding flight velocity, the lift coefficient. Hence, if the lift remains constant with increasing flight velocity, the lift coefficient must rapidly decrease. Fig. 8 shows lift coefficients of airfoil sections as functions of Mach number as measured in wind tunnel. No reliable data exist for the transsonic range between $M=0.85$ and $M=1.4$.

We can express the same phenomenon in another way. The lift produced by a wing is the result of the deflection of the air passing along the chord. As a matter of fact, the lifting force is the reaction of the air pushed downward in unit time. The main part of the lift is produced by the deflection of the air passing near to the lifting surface. The contribution of the outer parts is relatively small. Now if we have a throat condition, the amount of air passing in a given neighborhood of the wing surface ceases to increase with increasing flight velocity and therefore the lift will not increase at the same rate with the flight velocity as it did before.

The appearance of shock waves at flight velocities approaching the velocity of sound was observed both in flight and wind tunnel. It is the primary cause of the "premature increase" of the drag, i.e., the increase that occurs before the flight velocity reaches the velocity of sound. Fig. 9 gives measured values of the drag coefficient of airfoils as functions of Mach number. It was found that the mere presence of supersonic velocity in a certain region does not necessarily involve the occurrence of compression shocks. The flight velocity at which the compression shock first appears is called the "upper critical flight velocity." Its determination, i.e., the exact conditions for the first appearance of shock waves are the subject of extensive theoretical and experimental research work. However, most of the scientific investigations in this field can become common knowledge only after the war because of the close connection between such purely scientific problems and the design problems of airplanes able to fly at transsonic velocities.

Fig. 10 shows so-called "Schlieren" pictures of the flow over a curved surface simulating the conditions on the upper surface of an airfoil. Flow direction is from right to left. Black means expansion in flow direction, the white lines indicate sudden increase of density. Fig. 10*a* is taken at a low Mach number, 10*b* at $M=0.65$, 10*c* at $M=0.75$, 10*d* at $M=0.83$. The photographs also show that simultaneously with the occurrence of the shock wave the flow separates from the wing surface. This separation is the principal cause for the drag increase.

Obviously, it is an intriguing question whether there are any intrinsic limits for flight velocity. Many people will ask "Shall we ever fly faster than sound?" I do not believe that at the present time this question can be answered by a straight "yes" or "no." There is one case that can be treated in a rather simple way: the case of an airplane diving vertically. You may remember we have read several times in the news that one or another pilot claimed that he had reached while diving a speed faster than sound velocity. In the stationary state of vertical diving the weight of a falling body or a diving airplane is equal to the drag. As mentioned before, we usually express the drag D of the airplane by the product of the drag coefficient, C_D the wing area S, and the half product of the

density ρ and the square of the velocity v. Introducing the value of the velocity of sound by the formula $c^2=\gamma p/\rho$, this equation can be expressed also in the following form:

$$D=\frac{\gamma}{2}C_D S p M^2 \qquad (5)$$

i.e., the drag equals the product of the wing area, the atmospheric pressure at the altitude at which the diving is performed, the square of the Mach number multiplied with a numerical factor equal to $\gamma C_D/2$. Using the value $\gamma=1.405$ and putting the drag equal to the weight W of the airplane, we obtain the following expression for the value of the drag coefficient which permits a certain Mach number M to be reached in diving:

$$C_D=1.42\,\frac{W}{Sp}\,\frac{1}{M^2}. \qquad (6)$$

For diving at sound velocity, we have to substitute $M=1$ in this equation. The weight of the airplane divided by the wing area is called the wing loading l_w. Hence, we obtain for the maximum value of the drag coefficient which would permit diving at sound velocity the following simple expression:

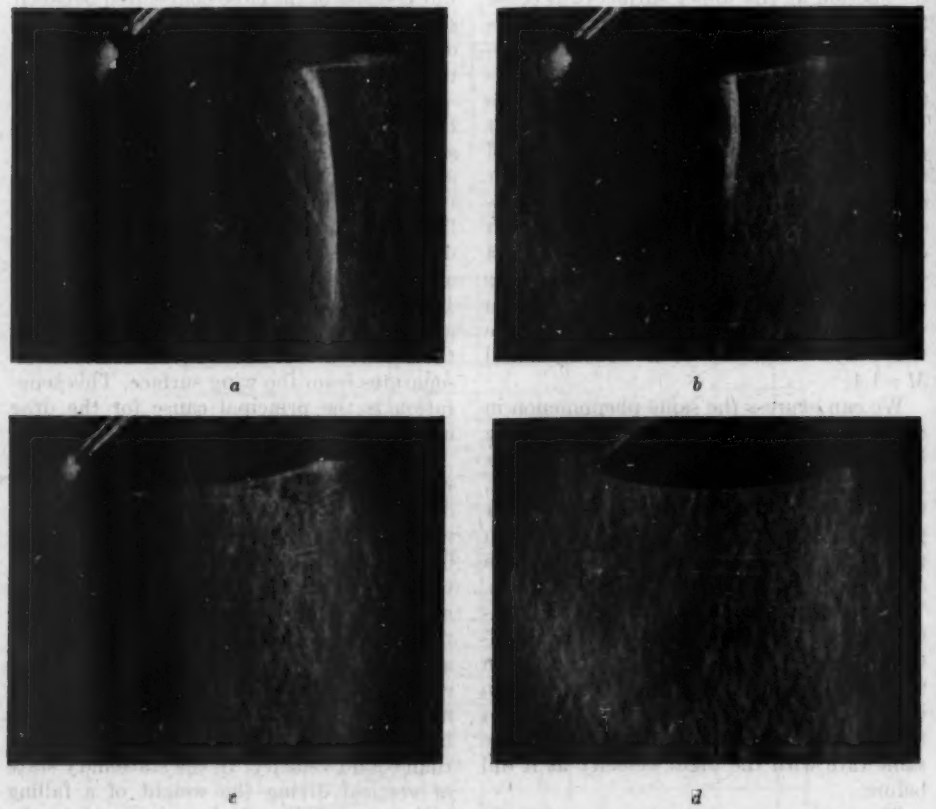

FIG. 10.—Schlieren photographs of flow past an elliptical cylinder with 0.15 thickness ratio at zero angle of attack. The direction of flow is from right to left. The small oblique channel visible in the pictures at the leading edge of the ellipse serves to remove the upstream wall boundary layer. Correct flow past the surface of an elliptical cylinder is thus obtained using only *half* of an elliptical section. Dark areas correspond to expansion, light areas to compression. Exposure time 1/25 sec.

$$C_D = 1.42 \frac{l_w}{p} \cdot \qquad (7)$$

Table 2 gives the values of the allowable maximum drag coefficient as function of altitude and wing loading. The wing load-

TABLE 2

Altitude (ft.)	Pressure (lb./ft.²)	Wing loading (lb./ft.²)			
		30	40	60	80
Sea level	2,106	0.0202	0.0269	0.0404	0.0538
10,000	1,448	0.0294	0.0392	0.0588	0.0784
20,000	908	0.0440	0.0586	0.0880	0.1172
30,000	626	0.0680	0.0906	0.1360	0.1812
40,000	390	0.1092	0.1456	0.2184	0.2912

ing of fast modern airplanes is of the order of 35 to 50 pounds per square feet; unmanned missiles have still higher wing loading. On the other hand, the drag coefficient at low speeds, i.e., low Mach numbers is reported to be about 0.02 for the Spitfire and about 20–25 per cent lower for some fast American fighters. It is seen that the question as to whether such an airplane can dive with sound velocity depends on the ratio between the drag coefficient at $M=1$ and at low Mach numbers, say $M \to 0$. There is no exact information available about this ratio. However, if we use ballistic data for estimating the ratio, it appears that we have a marginal case. It should not be impossible to make design alterations that would allow an airplane of the present general type to dive at a speed equal to the velocity of sound.

The case of level flight at transsonic and supersonic speeds is much more complex. The present official international world record is 468.94 m.p.h. (1939). To be sure, according to regulations the flight for the international speed record has to be performed at sea level. We do not know what maximum speed was reached actually in recent years. Probably the man who will first challenge the world record will have to prepare himself for a substantial step up. The problem is complex because reduction of the drag of the airplane is only less than half of the whole story. The question of weight is the most important point. First, of course, a certain percentage of the total weight is necessary for safe structure. Then the airplane has to carry the weight of the power plant and the weight of the fuel. The size of the power plant is determined by the thrust required to balance the drag, the weight of the fuel by the thrust required and the desired flight duration.

In general, the power plants of lighter weight for the same power output consume relatively more fuel. The power plants of high fuel economy are relatively heavier. The aerodynamic considerations give preference to high altitude; on the other hand, a power plant of a given weight will furnish, in general, less power at a higher altitude.

To some extent the question of supersonic flight is analogous to another intriguing problem discussed sometimes by serious men, more often by authors having more imagination than scientific knowledge. I mean the question of the feasibility of navigation off from the gravitational field of the earth. Of course, some fabulous new fuel would change the situation completely in both cases. However, basing the consideration on power plants and fuels which are available or which we hope to have with reasonable expectation, the answer to the question of the feasibility of stellar navigation is probably negative, whereas there is no evidence that the velocity of sound should constitute a "stone wall" of despair. To be sure, it will be necessary to use all good advice which aerodynamic science, chemistry of combustion, and thermodynamics may contribute.

We did not touch one question at all, a question that perhaps is fundamental: Why does anyone want to travel so fast? I think this question is too difficult for an engineer. It should be asked of a philosopher.

GEOCHEMISTRY.—*Contact deposits in an artificial silicate magma.*[1] HERBERT INSLEY, Pennsylvania State College.

It is my purpose here to give an example of how petrological laboratory methods may be applied to a technological problem and how in turn the solution of that problem affords some speculation on a question in petrogenesis. Much of the work referred to was done some years ago, but interest in it and in the petrogenetic speculations arising from it has lately been renewed because of war work on the corrosion of optical glass melting pots.

The technological problem in question was the determination of the cause of the corrosion and failure of refractories used in glass melting, and, therefore, a necessary part of the solution was the determination of the course of attack and the reaction products produced by the attack of molten glass on the walls of the tank used as container. The method used was the petrographic-microscopic examination of the contact zones of glass and container.

The molten glass in a melting tank is an artificial silicate magma and in general is not unlike a natural magma, although there are some marked differences in detail. The artificial and the natural are similar in that both are silicates, and the containing chambers of both are composed of similar materials. They differ in the details of their composition, the temperatures to which they are exposed, the time of exposure, the amount and character of the gaseous phase present, and the rate of flow of the magma in the basin.

The glass-containing portions of tanks are generally rectangular in plan and in elevation, varying in dimensions from one 25 feet long by 12 feet wide by 2 feet deep to one as large as 100 by 60 by 3 feet. The quantity of glass contained may range from 60 to 1,500 tons. The walls and floor of the tank which are in contact with the molten glass are essentially an aluminum silicate. Sometimes they are fired clay blocks and sometimes a mixture of alumina and silica fused and cast into blocks. The alumina-silica ratio of such refractories may vary over a wide range. The roof and upper side walls in contact with the tank atmosphere are generally made of silica brick with a silica content of more than 95 percent. The melting end of the tank is separated from the "refining" end by a refractory wall (the "bridge wall"), the molten glass passing from one section to the other by means of a submerged "throat."

The batch mixture consisting usually of alkali carbonate or sulphate, limestone, and quartz sand with the occasional addition of other substances is introduced into the melting end of the tank and melted by the radiant gases from burning producer gas, fuel oil, or natural gas passing over the surface of the tank. Melting temperatures of 1,450 to 1,500° are generally used. The reaction to form glass proceeds by the removal of carbon dioxide and the mutual solution of the alkalies, lime, and silica. Magnesia is sometimes substituted for part of the lime and additions or substitutions of other oxides such as alumina, lead oxide, barium oxide, etc., are frequently made. In the usual commercial window or bottle glass silica may range from 68 to 74 percent, soda from 11 to 17 percent, and lime from 8 to 14 percent. By comparison, the igneous rocks all contain much more alumina. Only the granite group contains as much silica and only the nephelite rocks as much alkali.

Unlike natural igneous rocks where complete vitrification is extremely rare the chief aim in the manufacture of commercial glass is the total elimination of crystalline material. Within the glass-melting tank itself some crystallization may take place in corners where circulation is poor or an accumulation of unmelted batch material and devitrified glass may be gathered behind the bridge, but the appearance of these materials in the finished glass will cause the rejection of the ware.

The reactions of the molten glass with

[1] Address by the retiring president of the Geological Society of Washington, delivered at the 51st annual meeting of the Society, December 8, 1943. Received February 5, 1945.

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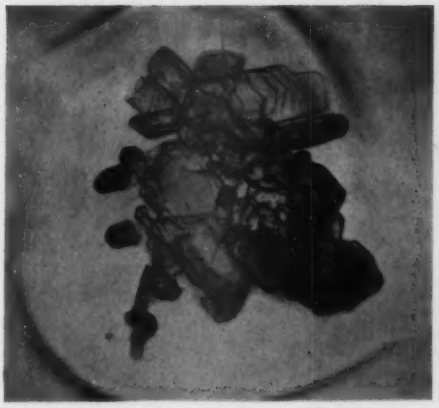

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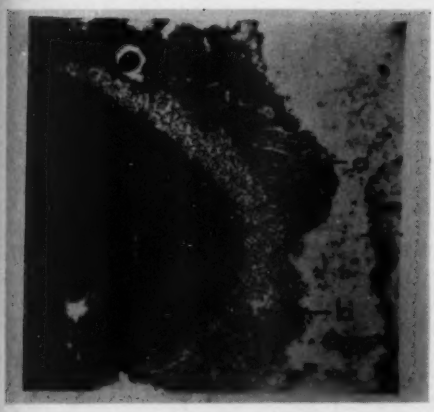

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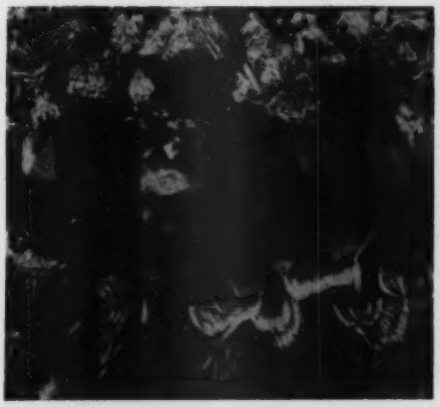

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FIG. 1.—Broken piece of clay refractory block after exposure to the atmosphere of the glass tank above the glass level showing dark crust of small crystals of corundum on outer surface (left) with bleached layer of vitrified refractory next and unattacked refractory below. About ½ natural size. FIG. 2.—Aggregate in glass of platy crystals of corundum in parallel arrangement probably originating in the crust on aluminum silicate refractory above the glass level and carried down into the glass with liquid silicate material. ×16. FIG. 3.—A "stone" of aluminum silicate refractory embedded in glass with an outer reaction rim of skeleton nephelite (marked "a") and an intermediate zone of thin platy crystals of corundum (appearing as needles in area marked "b"). ×50. FIG. 4.—A "stone" embedded in glass that was originally aluminum silicate refractory but that has been completely converted to nephelite by reaction with the glass. An outer zone of skeleton crystals with a core of complete nephelite crystals. ×40.

the walls of the container are interesting not only from the point of view of the glass manufacturer, who is concerned with the durability of the glass tank and the purity of the glass produced, but also from the point of view of the petrologist and the silicate chemist. The corrosion of the tank walls weakens the container by loss of materials and also introduces crystalline reaction products and undissolved wall material into the glass.

That part of the aluminum silicate refractory above the level of the molten glass is subject to reaction with the tank atmosphere. This atmosphere contains the unburned fuel gases and the products of combustion as well as volatilized alkalies and the batch dusts composed largely of alkali carbonates with smaller amounts of the coarser-grained quartz and limestone. Usually the ratio of alkalies to lime and silica is much higher in the tank atmosphere than in the molten glass. The action on the aluminum silicate refractory above the glass level is in general a decomposition to form crystalline alumina (αAl_2O_3 or corundum) in a liquid sodium calcium aluminum silicate. On vertical or sloping side walls the platy crystals of corundum tend to form a network from which the silicate liquid drains away into the glass in the tank often leaving a thick crust of corundum crystals (Fig. 1). At times the corundum crystals are carried into the tank glass with the liquid silicate to form troublesome and relatively insoluble "stones." Where the liquid is retained on the refractory wall it may sometimes crystallize to a plagioclase feldspar[2] or, more rarely, to nephelite ($NaAlSiO_4$).

The reaction to form corundum and liquid (Fig. 2) in the aluminum silicate refractories exposed to the glass furnace atmosphere at operating temperatures takes place even though the refractory block has a composition more highly siliceous than that of a pure dehyrated kaolinite (Al_2O_3—46 percent, SiO_2—54 percent) where one might reasonably expect an aluminum silicate such as mullite to form. A consideration of the solubility relations in the system, Na_2O–Al_2O_3–SiO_2 (Fig. 5[3]) at these temperatures shows the reason for the phases present. The boundary of the primary phase fields of mullite ($3Al_2O_3 \cdot 2SiO_2$) and corundum (Al_2O_3), which in the Al_2O_3–SiO_2 system lies at a SiO_2/Al_2O_3 ratio, is 78/22 and the Na_2O percentage is about 10. This represents a deep salient of the corundum primary phase field into the ternary system and in effect means that at the operating temperatures of glass tanks corundum may be the product of reaction between aluminum silicate and soda where the original blocks were considerably higher in silica than kaolinite and which, therefore, may have contained originally considerable quartz. Moreover, close to the quintuple point albite-mullite-corundum-liquid-vapor the isotherms (not shown on the diagram reproduced) indicate that corundum may be a product of crystallization from the liquid at temperatures as low as 1,100°, although there is a very sharp increase in liquidus temperatures toward the Al_2O_3 apex of the diagram. The diagram of the K_2O–Al_2O_3–SiO_2 system[4] indicates the same strong inclination of the corundum-mullite boundary toward the silica apex as in the Na_2O–Al_2O_3–SiO_2 system. In the CaO–Al_2O_3–SiO_2 system[5] the inclination of the mullite-corundum boundary is also toward the SiO_2 apex, although it is not nearly as pronounced as in the other two diagrams.

Approximately the same reaction products are formed at the contact of molten glass and aluminum silicate refractory as are formed above the level of the molten glass, although the relative quantities are

[2] Feldspar crystals of the composition of oligoclase and labradorite have been observed.

[3] The figure shown is reproduced by the kind permission of J. F. Schairer, of the Geophysical Laboratory, and represents his tentative and as yet unpublished data on this system. Although later work may change some details of the diagram, he does not believe that any changes of significance to this discussion will be made in the final form.

[4] Reproduced in N. L. BOWEN's *Petrology and silicate technology*, Journ. Amer. Cer. Soc. 26: 285–301. 1943.

[5] As modified from RANKIN and WRIGHT, Amer. Journ. Sci. 39: 1–79. 1915; BOWEN and GREIG, Journ. Amer. Cer. Soc. 7: 238. 1924; and GREIG, Amer. Journ. Sci. 13: 35–41. 1927; and summarized in HALL and INSLEY, Journ. Amer. Cer. Soc. 16: 524. 1933.

much different largely because of the fact that considerably greater percentages of silica and lime take part in the reaction in the former case than in the latter. In the reaction between glass and refractory, moreover, both of the reaction products, corundum and liquid, are carried away from the reaction face, thus continually exposing new material to attack. In fact, both above and below the glass line the reaction is a non-equilibrium process even over very short distances. Mullite and glass are the products produced in the manufacture of the refractory. In refractories below the glass level the first evidence of the reaction of the molten glass is shown by an increase in the amount of glass with respect to that of mullite with the eventual appearance of tabular rhombohedral crystals of corundum. The outer portion of the corundum layer (next to the glass) frequently contains skeleton crystals of nephelite (Fig. 3), sometimes associated with carnegieite. In the melting end of the tank the temperatures are generally far too high to permit the formation of the nephelite-carnegieite phase, and here the crystallization probably takes place during the cooling of the tank after a campaign. In the cooler portions of the tank operating temperatures are frequently within the range in which these compounds may crystallize. Below the glass level, as well as above, corundum crystals may form as a reaction product on refractories in which the Al_2O_3/SiO_2 ratio is considerably below that of kaolinite (46/54). Even a refractory material that contains enough excess silica for considerable free quartz may

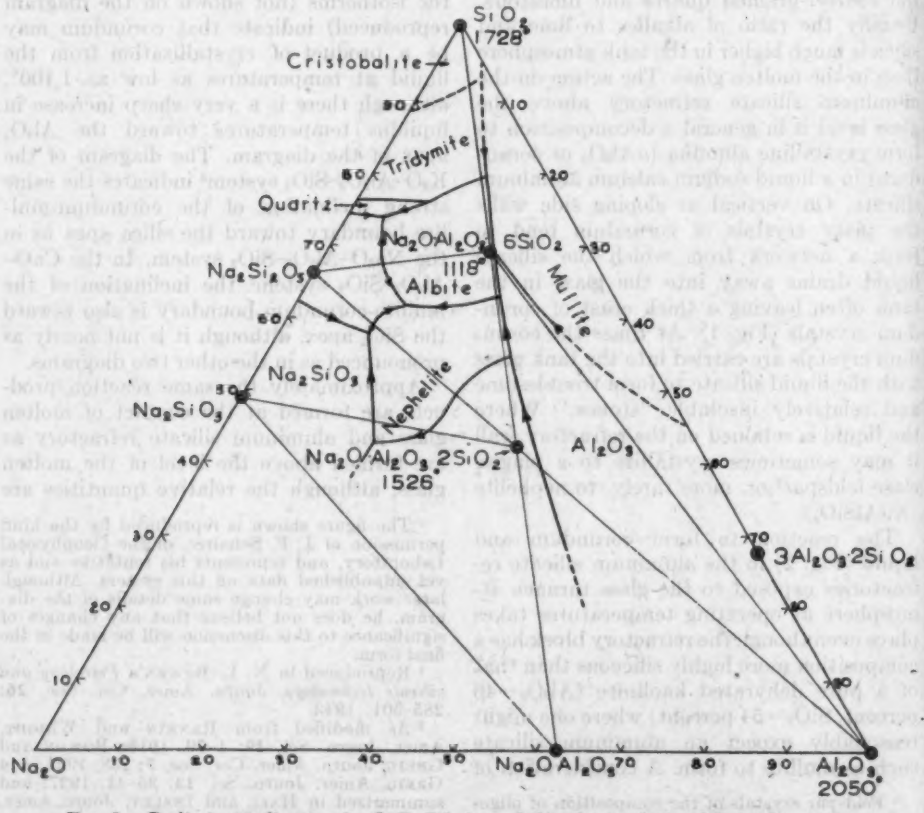

FIG. 5.—Preliminary diagram by J. F. Schairer of the phase relationship in the system Na_2O–Al_2O_3–SiO_2. Reproduced with permission from unpublished data.

produce corundum with the molten glass. In xenoliths of refractory material which have been carried away in the magma varying degrees of metamorphism and digestion have been observed. Pieces that have broken from the refractory near the exit end of the tank and presumably exposed to reaction at fairly low temperatures (very approximately 1,100°C.) for a short time may have slight evidences of solution of the mullite crystals with a few extremely thin corundum crystals at the contact. In others which have undergone longer attack at higher temperatures the mullite crystals have disappeared completely, and the inclusion has a core composed of a mass of small corundum crystals in a matrix of nephelite with an outer zone composed of almost pure nephelite. Where reaction has gone still further, the corundum crystals have disappeared completely, and nephelite is the only crystalline material remaining (Fig. 4). "Stones" showing all these stages of reaction have been gathered from a glass melting tank which has been closed down for repairs of the badly corroded refractories after a long melting period.

A partial substitution of potash for soda, as is the case in some commercial and in some optical glasses, produces the same general reaction products with the refractories. The feldspathoid associated with corundum is in this case a nephelite-kaliophilite solid solution. In lead-containing optical glasses corundum also is a product of the reaction between molten glass and refractory even in the absence of alkalies.

The solution of the technological problem of increasing the resistance of the refractory to corrosion by molten glass would appear to be simple from the purely chemical point of view after the products of the reaction have been identified. A moderate increase in the alumina content of the refractories may, however, do more harm than good, because solution of the more soluble phase in the molten glass may release abundant, relatively insoluble corundum crystals into the glass and cause the rejection of the ware because of "stones." If the refractory can be made out of homogeneous, nonporous, pure alumina, then whatever slight solution there is will be uniform and do little or no damage to the glass. Technical difficulties in the manufacture of a mechanically stable refractory of this type are numerous, however, and so far it has not been satisfactorily solved.

The fact of the occurrence of corundum as a contact metamorphic deposit in an artificial igneous magma at once brings up the question of its pertinence to the origin of corundum deposits in nature. It is notable that practically all deposits whose geological relationships are at all clear are in, or are closely associated with, igneous bodies and that, with one notable exception, these deposits occur sharply localized at the contact with the country rock or in association with partly digested xenoliths. The exception is the group of Ontario corundum bodies.

The deposit in nature that most nearly approximates that in the glass tank with respect to the composition of the intrusive magma and the absence of pneumatolytic or hydrothermal effects is undoubtedly that at Nun's Pass in the Island of Mull described by H. H. Thomas.[6] Here the central felsitic portion of the invading magma in the sill has a composition of about 71 percent SiO_2, 12 Al_2O_3, 3.5 FeO, 1.3 CaO, 4.7 K_2O, and 2.5 Na_2O, which is not greatly different from that of commercial glass. The invading rock lining the walls is of a somewhat different character. On one wall it is characterized by cognate, on the other by accidental xenoliths. The accidental xenoliths are the important ones in this connection. In part they are buchites containing mullite and cordierite in glass astonishingly similar in texture to the matted mullite needles in the glass tank refractory in the first stages of attack by the molten glass. The most abundant accidental xenoliths, however, are those containing assemblages of corundum, spinel, anorthite, and a small amount of interstitial glass with the anorthite often acting as a matrix for the corundum and spinel. Even the rock acting as host for the xenoliths is so contaminated by introduced material that Thomas does not consider it as a truly igneous rock. The xenoliths are thought by Thomas to be formed by the direct fusion

[6] Quart. Journ. Geol. Soc. 78: 229. 1922.

of highly aluminous sediments in the magma, although the effect of the alkalies would be to lower markedly the SiO_2/Al_2O_3 ratio at which corundum could form.

There are other corundum occurrences that provide a somewhat less perfect analogy to the glass-melting tank. In the Eifel district in Germany hornblende andesites contain included fragments or streaks composed of cordierite, sillimanite, feldspar, corundum, etc., which are considered to be crystalline schists that have been partly digested and recrystallized. In the Herz Mountains a biotite-plagioclase dike intrusive into clay slates contains cordierite, garnet, cyanite, sillimanite, and corundum, which are not characteristic of any purely igneous rock. A number of other occurrences can be cited where rocks varying from granites to andesites, diorites, and nepheline syenites are closely associated with, or evidently intrusive into, clay-bearing rocks with corundum in the intruded rock, the intrusive rock, or both. The chemical and phase relationship pointed out in the systems Na_2O–Al_2O_3–SiO_2 and CaO–Al_2O_3–SiO_2 seem adequate to explain the origin of corundum in these cases. Whether the formation of corundum is the result of contact metamorphism and recrystallization with the intervention of very little liquid phase, or whether the clay-bearing rocks have been partially digested in the igneous solution and then recrystallized, appears to be of no fundamental importance. The point is that localized reaction has taken place with rocks that, although, of course, aluminous, need not have any higher Al_2O_3/SiO_2 ratio than ordinary clay, i.e., $Al_2O_3/2SiO_2$ molecularly. The presence of aqueous solutions at high temperatures and pressures need cause only a lowering in the temperature at which the reactions take place, and the solubility relations expressed by the bending of the mullite-corundum boundary toward the silica apex which exist in the anhydrous system may also exist in the presence of water.

The contact relations in some other deposits of corundum associated with alkaline rocks cannot be so clearly visualized nor the crystallization so definitely connected with phase relations in the alkali-alumina-silica systems. In the Ontario deposits where corundum bodies are developed in syenites, nepheline syenites, and anorthosites Barlow[7] postulated that corundum crystallized directly from a high alumina magma and based his deduction on the relationships found by Morozewicz[8] in some empirical laboratory experiments on artificial melts. No one has so far, however, proposed any hypothetical line of petrologic descent from any of the conventional parent magmas that would result in the crystallization of free alumina and its concentration by any process of magmatic differentiation. Barlow, himself, emphasizes the fact that the Ontario corundum deposits, although relatively large, are extremely localized and that the host rocks are chiefly notable for extreme and rapid variation in composition and mineral assemblages. These are not characteristics of crystallization from an originally homogeneous magma even with later crystal sorting. May not the Ontario deposits represent a later stage in a process like that which operated in the Nun's Pass rocks? Although no source of the aluminous sediments was found in the latter case, the relationships in the final rock were such that this genesis could not be doubted. In the Ontario rocks the source of the sediments may have been further removed and the progress toward homogeneity somewhat more advanced.

The case of the association of corundum deposits with basic rocks like the peridotites and norites is more difficult to explain. Additions of neither magnesium metasilicate nor magnesium orthosilicate to alumino silicates of the composition of the quadruple point (approximately $54Al_2O_3$, $46SiO_2$) bring the mixtures within the regions where corundum is either a final or intermediate product of crystallization. The presence of ferrous oxide in the olivines or of alkalies in the alumino silicates may alter the relations sufficiently to permit

[7] A. E. Barlow, Canada Dept. Mines, Geol. Survey, Memoir 57. 1915.

[8] J. Morozewicz, Tschermak's Pet. Mitt. 18: 1–90. 105–240. 1898.

corundum to crystallize. It has also been pointed out in the case of the corundum deposits occurring with dunite in North Carolina that the mineral associates of the corundum are those characteristic of hydrothermal metamorphism.[9] It may be that water at elevated temperatures and pressures can also reverse the trend of the mullite-corundum boundary in systems with magnesia. A few preliminary high-temperature experiments with additions of ferrous oxide, water, or both should demonstrate whether the production of corundum is possible under these simplified composition relationships. The rather constant association of granitic gneiss or clay schist country rock with the corundum that is formed at the borders of basic magnesian rocks can hardly be accidental, and the source of the corundum would logically appear to be the reaction of the intruding and intruded rocks whether or not water vapors or other "mineralizers" take part in this reaction.

These remarks can be summarized briefly. It has been shown that corundum is formed in a glass-melting furnace by the action of a melt containing large amounts of silica and alkalies and considerable lime on an aluminum silicate wall material that approximates dehydrated kaolin in composition and that the formation of corundum under these conditions is explained by the phase relationships in the system Na_2O–Al_2O_3–SiO_2. It is pointed out that the origin of corundum at the contact of syenites and nepheline syenites with aluminum silicate country rocks may be similar and that whether the corundum forms by localized digestion and crystallization from solution or by reaction essentially between the solids is a difference in degree and not in kind. Moreover, the country rocks do not have to be abnormally high in alumina, since in the case of glass tanks, at least, alumina-silica ratios lower than that of kaolin are sufficient to produce corundum by reaction. In the case of the reaction of highly basic magnesian magmas (peridotites and the like) with wall rock the reaction relations are less easy to understand. Nevertheless, the reaction relations must not differ radically from those found in the case of alkaline magmas even though water becomes a necessary agent in the reaction.

[9] E. S. LARSEN, Econ. Geol. 23: 398–433. 1928.

NOTE: Since this address was delivered, a paper by W. K. Gummer (Journ. Geol. 51: 503–530. 1943) on the system $CaSiO_3$–$CaAl_2Si_2O_8$–$NaAlSiO_4$ shows that crystalline alumina (βAl_2O_3 in this case) can exist at the liquidus on the join between $NaAlSiO_4$ (nephelite) and $CaAl_2Si_2O_8$ (anorthite) as well as at the liquidus in the ternary system $CaSiO_3$–$NaAlSiO_4$–$CaAl_2Si_2O_8$. The petrologic significance is discussed in the paper.

BOTANY.—*Irregular barley*, Hordeum irregulare, *sp. nov.*[1]

EWERT ÅBERG, University of Wisconsin and Bureau of Plant Industry, Soils, and Agricultural Engineering, and G. A. WIEBE, Bureau of Plant Industry, Soils, and Agricultural Engineering. (Communicated by M. N. POPE.)

One of the types of barley endemic to Abyssinia is best described by a single word, irregular. The late Dr. H. V. Harlan used this term in 1914 (*6*, p. 24) when he stated: "Aside from the observations upon established forms, it has been the fortune of the writer to isolate a number of which there seem to be no published descriptions. These all came from Abyssinian barleys, and as the work is not yet completed, only a general indication of the results need be given here. . . . In barleys received from the same region, there is a group with a curious,

[1] Received February 22, 1945. Cooperative investigations between the Wisconsin Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture. Published with the approval of the Diector of the Wisconsin Agricultural Experiment Station. Supported in part by a Research Grant from the Wisconsin Alumni Research Foundation.

irregular, yet heritable, habit of floret abortion. In the ripened spike the spikelets are normal at the base and for a varying distance toward the tip. The upper portion usually reduces suddenly to a 2-rowed form. In this case the lateral spikelets are not merely sterile, but are reduced to only the outer glumes and the rachilla, the floret having disappeared entirely. The spikes are found to present these modifications even when the head first emerges from the boot. The actual time of the reduction has not been determined but it is so early that no scar is present, indicating that the floret never started to develop."

Harlan continued orally to use the term, irregular barleys, for the type he described in 1914, but unfortunately it never became established in the literature nor came into general use. This is to be regretted, as there is a real need for this term in the barley classification, and especially so since the terms which have gradually come into use instead are confusing and not at all as descriptive as the one Harlan applied.

It appears that the irregular type of Abyssinian barley was collected once by A. F. W. Schimper in the middle of the nineteenth century. It was grown by Al. Braun in the Botanical Garden at Freiburg in 1848, but at that time it was regarded only as a transition form between 6-rowed and 2-rowed barley. This is evident from a statement in "Sitzungsberichte des botanischen Vereins der Provinz Brandenburg" published in 1875 (*12*, p. 437). There it is stated: "Herr Wittmack legte eine grössere Zahl von Schimper in Abyssinien gesammelter Gerstenähren vor, die er theilweise von Herrn Prof. Braun, theilweise von Herrn Dr. Grönland erhalten hatte, und wies an mehreren den Uebergang von 4-zeiliger Gerste[2] in zwei-zeilige nach, ein Uebergang, der bei unseren Culturen sich nie zeigt, aber bei den vom Prof. Braun in Freiburg i/Br. 1848 angestellten Aussaatversuchen der abyssinischen Gersten widerkehrte." The fact that this Abyssinian type appears morphologically to occupy an intermediate position between 6-rowed and 2-rowed barley later undoubtedly led to the use of the term "intermediate" and also to the Latin name *Hordeum intermedium*, although the latter never was intended for that type.

In 1882 Körnicke (*8*, pp. 185–186) described as *Hordeum vulgare* L. subsp. *intermedium* a barley type with awned central florets and awnless lateral ones. The lateral seeds are markedly smaller than the central ones but germinate when seeded. In 1885 Körnicke (*9*, pp. 172–174) gives the same description, only adding that in one of the varieties of the subspecies, var. *Haxtoni* Kcke., not all lateral florets are fertile. The florets are, however, fully developed. In 1916 Carleton (*3*, p. 124) and in 1918 Harlan (*7*, p. 12) used the same description for the species *Hordeum intermedium* Kcke. Harlan's description of *Hordeum intermedium* in 1918 does not include the irregular type of Abyssinian barley that he discussed in 1914. The first time this type is again mentioned in the literature is by Engledow in 1924. Previous to that date it was discussed in correspondence between Harlan and Engledow.[3] Judged from a letter to Harlan on January 29, 1921, Engledow had found the irregular type among Abyssinian barleys in 1920. From Harlan's reply on February 23, 1921, it is clear that Harlan, at that time, knew about the variations in irregular barleys from the type with occasional lateral seeds to those with practically all lateral seeds fully developed, but he did not classify them with any other group of barleys. Engledow's description in 1924 places the irregular barleys as exceptional forms of *Hordeum hexastichum* or *Hordeum decipiens*. He placed them with *Hordeum hexastichum*, when an occasional lateral floret was missing, and with *Hordeum decipiens*, when many of the lateral florets were missing. In regard to the stability of the character he points out (*4*, p. 58), that "in three successive seasons this peculiarity has been maintained and it is, therefore, to be regarded as a constant and heritable attribute."

Körnicke's description of *Hordeum vulgare* L. subsp. *intermedium* remained valid and was applied only to the type of barley

[2] The "4-zeilige Gerste" in the early literature is equivalent to the 6-rowed barley of the present-day literature.

[3] Correspondence between Harlan and Engledow filed in National Archives, Washington, D.C.

FIG. 1.—Spikes of irregular barley, *Hordeum irregulare* E. Åberg and Wiebe, of Abyssinian origin showing the variation found in number of missing lateral florets. *A*, Many lateral kernels missing (C. I. 5843); *B*, some lateral kernels missing (C. I. 3210–5); *C*, occasional lateral kernels missing (C. I. 1238).

for which it was intended, even during the period when Harlan and Engledow worked with irregular Abyssinian barleys. In 1929, when Orlov gave a description of barleys from Abyssinia and Eritrea, he brought the irregular barleys in under the subsp. *intermedium* Kcke. (*10*, pp. 317–333, 344–345), thereby causing considerable confusion. According to his description of subsp. *intermedium* Kcke., the lateral spikelets may be fertile or sterile, in the latter case consisting of glumes, lemma and palea, or they also may be completely reduced so that only the glumes are developed. Considerable variation occurs in the number of fertile and sterile spikelets on the spike, which is useful as a means of classifying varieties. No mention is made of the type of awn on the lemmas of central and lateral florets.

In 1936 Orlov (*11*, pp. 228–229) included the irregular barleys under subsp. *intermedium* Vav. et Orl. (subsp. nov.) and pointed out that this subspecies is sharply distinguished from subsp. *intermedium* Kcke. The characteristics for subsp. *intermedium* Vav. et Orl. are that a varying number of spikelets (one, two, or three) with normal kernels develop at each node of the rachis of the spike. See also Åberg (*2*, p. 18).

As editor of the Russian publication *Classification of Cereals*, Flaksberger pointed out in an editor's note (*5*, p. 342) that he thought it would have been more nearly correct for Orlov to have retained the use of subsp. *intermedium* Kcke., for the intermedium group of barleys as described by Körnicke. Flaksberger also suggested that *interjectum* could be used for the Abyssinian intermediate barleys (irregular as used in this paper).

Unaware of Harlan's suggestion and continued use of the term "irregular," for the Abyssinian intermediate type, Åberg (1940) also applied *Hordeum intermedium* (Kcke.) Carleton to barley of this type (*1*, pp. 102–106).

From this review it is evident that there is a great deal of confusion among workers in the use of these terms. The Latin name *Hordeum intermedium* has been applied to two types of barleys that in reality are distinct. The terms intermedium, intermediate, and Abyssinian intermediate are used and each has a very definite and specific meaning. Unfortunately, however, they sound very nearly alike and appear very similar in print.

It seems desirable, therefore, to make the following disposition: (1) Retain "*intermedium*" essentially as used by Körnicke in *Hordeum vulgare* L. subsp. *intermedium* for that type of 6-rowed barley in which the lateral kernels are reduced in size and their lemmas awnless. It is further suggested that Körnicke's subspecies be regarded as a variety and used as *Hordeum vulgare* L. var. *intermedium* Kcke. (2) Use the term "intermediate" in a broad sense to describe plant characters that are midway between extremes or limits, as, for example, leaf size may be intermediate; and also to describe in a broad way heterozygous genetic types like the F_1 of a 6-rowed $\times$2-rowed barley cross. (3) Replace "Abyssinian intermediate" with "irregular," which latter name was suggested by Harlan as early as 1914. To achieve this the irregular barley, which have been erroneously included under "*Hordeum intermedium*," are here segregated as distinct and described as a new species as follows:

Hordeum irregulare, sp. nov.

Rhachi spicae dura; spiculis centralibus fertilibus, lateralibus aliis fertilibus aliis sterilibus, aliisque sine staminibus vel pistillis pro parte ad rhachillas in spicam irregulariter dispositas reductis.

Irregular barley with tough rachis. The central florets fertile; lateral florets reduced to rachilla in some cases and these distributed irregularly on the spike, the rest of the lateral florets of only one of the following types: fertile, sterile, or sexless (Figure 1).

Type: No. 161999, herbarium of the U. S. National Arboretum, grown at Plant Industry Station, Beltsville, Md., February 1945, from seed collected by H. V. Harlan at Lalibela market, Abyssinia, on January 7, 1924, from cultivated plants. (C. I.[4] No. 3908-3, Division of Cereal Crops and Diseases, Bureau of Plant Industry Station, Beltsville, Md.)

[4] C. I. refers to accession number of the Division of Cereal Crops and Diseases.

According to the above, the division of the section *Cerealia* Ands. of the genus *Hordeum* L. as given by Åberg (*1*, p. 119) is revised as follows:

H. agriocrithon E. Åberg
H. spontaneum C. Koch
H. vulgare L. emend. Lam.
H. irregulare E. Åberg and Wiebe
H. distichum L. emend. Lam.

LITERATURE CITED

(1) Åberg, E. *The taxonomy and phylogeny of* Hordeum L. *sect.* Cerealia *Ands.* Symb. Bot. Upsalienses **4**: 156 pp., illus. 1940.

(2) ———. *The classification of subspecies and varieties of* Hordeum sativum *Jessen.* (Extracts from the paper on barley by A. A. Orlov, published in Russian in *Flora of Cultivated Plants II*, Moscow-Leningrad, 1936.) Fedde Repertorium **50**: 18. 1941.

(3) Carleton, M. A. *The small grains*, 699 pp., illus. New York, 1916.

(4) Engledow, F. L. *Inheritance in barley. III.* Journ. Genetics **14**: 57–58, 60–62, illus. 1924.

(5) Flaksberger, K. A. *Editor's note in:* Bakhteyev, F. Kh., Hordeum L. *Barley. Classification of Cereals*, ed. 4, illus. Moscow-Leningrad. 1939.

(6) Harlan, H. V. *Some distinctions in our cultivated barleys with reference to their use in plant breeding.* U. S. Dept. Agr. Bull. 137, 38 pp., illus. 1914.

(7) ———. *The identification of varieties of barley.* U. S. Dept. Agr. Bull. 622, 32 pp., illus. 1918.

(8) Körnicke, Fr. *Die Saatgerste.* Zeitschr. Gesam. Brauw. Neue Folge, V Jahrg., pp. 125, 185–186, illus. 1882.

(9) ———. *Die Arten und Varietäten des Getreides. In* Körnicke und Werner: *Handbuch des Getreidebaues* 1, 470 pp., illus. Berlin, 1885.

(10) Orlov, A. A. *The barleys of Abyssinia and Eritrea.* Bull. Appl. Bot. **20**: 283–345, illus. (English summary pp. 343–345). 1929.

(11) ———. Hordeum L. *Barley* (In Russian. Parts of it in translation by Åberg, 1941). *Flora of Cultivated Plants. II.* 447 pp., illus. Moscow-Leningrad, 1936.

(12) *Sitzungsberichte des botanischen Vereins der Provinz Brandenburg.* Bot. Zeit., 1875: 437–438.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE ACADEMY

NEW MEMBERS

There follows a list of persons elected to membership in the Academy by vote of its Board of Managers, during the Academy year 1943, who have since qualified as members in accordance with the bylaws of the Academy. The bases for election are stated with the names of the new members.

RESIDENT

William Sidney Benedict, physical chemist, Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C., in recognition of researches in the spectroscopy of polyatomic molecules and application of spectroscopy to kinetic studies of mixtures of isotopes.

Merrill Bernard, supervising hydrologist, U. S. Weather Bureau, Washington, D. C., in recognition of original researches in hydrology.

Clifford Allen Betts, engineer, U. S. Forest Service, Washington, D. C., in recognition of contributions to the development of hydraulic structures, including research on the generation of heat in concrete and the design of water tunnels.

Charles Louis Critchfield, mathematical physicist, Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C., in recognition of contributions to the theory of nuclear forces in atoms.

Lloyd George Henbest, associate geologist, U. S. Geological Survey, Washington, D. C., in recognition of work on micropaleontology, particularly the fossil Protozoa, and on stratigraphy.

Joseph Oakland Hirschfelder, assistant professor of chemistry, University of Wisconsin; consultant, National Defense Research Committee, Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C., in recognition of work on the equations of state of gases and liquids, reaction kinetics, and molecular quantum mechanics.

Emery Clarence Leonard, botanist, U. S. National Museum, Washington, D. C., in recognition of work on the flora of Haiti and on the mosses and Acanthaceae.

Glenn Lane Parker, chief hydraulic engi-

neer, U. S. Geological Survey, Washington, D. C., in recognition of services in the field of water supply engineering, and in particular the development of techniques for making water supply, storage power, and irrigation analyses.

CHARLES ELMER RESSER, curator of invertebrate paleontology and paleobotany, U. S. National Museum, Washington, D. C., in recognition of work in Cambrian stratigraphy and paleontology.

ROGER GORDON BATES, associate chemist, National Bureau of Standards, Washington, D. C., in recognition of contributions to the physical chemistry of electrolytes, and in particular researches on the thermodynamics of bi-univalent electrolytes and the pH values of standard buffer solutions.

SAMUEL WHITTEMORE BOGGS, geographer, United States Department of State, Washington, D. C., in recognition of contributions to political geography and cartography.

DONALD CLARKE BOUGHTON, zoologist, Bureau of Animal Industry, Beltsville Research Center, Beltsville, Md., in recognition of contributions to our knowledge of coccidia and coccidiosis of birds and livestock.

ELBERT LUTHER LITTLE, Jr., senior dendrologist. U. S. Forest Service, Washington, D. C., in recognition of distinguished services in the biological sciences, especially in the fields of forest ecology and dendrology.

GEORGE C. MANOV, assistant chemist, National Bureau of Standards, Washington, D. C., in recognition of contributions to physical chemistry, and in particlar work in thermodynamics and in the determination of pH values of standard buffer solutions.

HENRY STEVENS, principal biochemist, Bureau of Agricultural Chemistry and Engineering, U. S. Department of Agriculture, Washington, D. C., in recognition of fundamental and pioneering application of methods of immunochemistry to agricultural problems with particular reference to gossypol and other problems of sensitiveness connected with cotton.

HOWARD BANCROFT ANDERVONT, principal biologist, National Cancer Institute, Bethesda, Md., in recognition of original investigations in the fields of filterable viruses and experimental cancer.

HUGO BAUER, chemist, National Institute of Health, Bethesda, Md., in recognition of chemical advances in chemotherapy.

HAROLD WILLIAM CHALKLEY, senior physiologist, National Cancer Institute, Bethesda, Md., in recognition of services to the science of biology, particularly work on the physiology and chemistry of cell divisions.

HELEN M. DYER, research fellow, National Cancer Institute, Bethesda, Md., in recognition of contributions to research in chemotherapy, metabolism of sulphur-containing amino acids, and cancer studies.

WILTON ROBINSON EARLE, senior cytologist, National Cancer Institute, Bethesda, Md., in recognition of outstanding researches in the technique and study of tissue culture, in particular studies of the production of malignant cells from normal fibroblasts by the action of a chemical carcinogenic agent.

JOHN FEE EMBREE, senior archivist, War Relocation Authority, Washington, D. C., in recognition of studies of village communities in Hawaii, which led to important work for the Office of Strategic Services, and for the War Relocations Authority on the Japanese in America.

EMILY WALCOTT EMMART, associate cytologist, National Institute of Health, Bethesda, Md., in recognition of the publication of the Badianus Manuscript, and especially for accomplishments in research (1) in the application of tissue culture techniques to the study of cancer and (2) in the culture of the tubercle bacillus on animal membranes, the latter making possible a rapid and effective method for studying drug therapy.

MARGARET DOROTHY FOSTER, associate chemist, U. S. Geological Survey, Washington, D. C., in recognition of work on the geochemical relations of ground waters in the Coastal Plain and improvements in methods for the analysis of minerals.

MICHAEL FLEISCHER, geochemist, U. S. Geological Survey, Washington, D. C., in recognition of work in inorganic and mineralogical chemistry.

MAURICE THEODORE JAMES, associate entomologist, Bureau of Entomology and Plant Quarantine, Washington, D. C., in recognition of contributions to the taxonomy of insects.

SOLOMON KULLBACK, cryptanalyst, Signal Corps, U. S. Army, Washington, D. C., in recognition of contributions to mathematical statistics.

DAVID GOODMAN MANDELBAUM, Division of

Special Information, Office of Strategic Services, Washington, D. C., in recognition of contributions to the Ethnology of the Cree Indians of Canada; the Social Organization of South India tribes; and important work for the Office of Strategic Services.

MONROE HARNISH MARTIN, associate professor of mathematics, University of Maryland, College Park, Md., in recognition of contributions to mathematics, in particular to the "three body problem" in Celestial Mechanics.

ALBERT NELSON SAYRE, senior geologist, U. S. Geological Survey, Washington, D. C., in recognition of investigations in geology and hydrology, especially in regard to the occurrence of ground water in Texas.

FLORENCE MARIE MEARS, associate professor of mathematics, George Washington University, Washington, D. C., in recognition of contributions to the theory of infinite series, wherein research of recognized merit has been done.

MURRAY J. SHEAR, principal biochemist, National Cancer Institute, Bethesda, Md., in recognition of investigations on physico-chemical mechanisms of bone formation; carcinogenesis by chemical compounds; and chemical treatment of tumors.

DEMITRI BORIS SHIMKIN, Major, U. S. Army, Military Intelligence Service, East European Division, Washington, D. C., in recognition of contributions to the ethnology of the Wind River Shoshone Indians, theoretical works on problems of interaction of culture and personality; and important research on Siberia for Military Intelligence Service.

HERBERT CECIL SPICER, associate geophysicist, U. S. Geological Survey, Washington, D. C., in recognition of work in geophysics and geophysical methods of investigation.

ROLLIN ELBERT STEVENS, chemist, U. S. Geological Survey, Washington, D. C., in recognition of work in mineralogical and geological chemistry.

JOSEPH MANSON VALENTINE, associate entomologist, U. S. Bureau of Entomology and Plant Quarantine, Washington, D. C., in recognition of basic work on the classification of Coleoptera, and more especially contributions on speciation and raciation in insects.

CHESTER BURLEIGH WATTS, principal astronomer, U. S. Naval Observatory, Washington, D. C., in recognition of the invention of various devices for increasing the precision of observation of star positions; development of accurate methods for transmitting time signals with especial application to longitude determinations; and determinations of precise positions of comets, planets, and the moon.

FRANCIS JOSEPH WEISS, consultant, Board of Economic Warfare, Washington, D. C., in recognition of work in the fields of chemical economics; world crop insurance; utilization of waste products; economic development and planned utilization of Alaskan resources; chemical utilization of peat and seaweed.

MAXWELL MCMICHAEL KNECHTEL, geologist, U. S. Geological Survey, Washington, D. C., in recognition of work on the geology of (1) mineral fuels in Angola, Venezuela, Montana, and Oklahoma; (2) ground water in southeastern Arizona; (3) Pleistocene glacial phenomena in northcentral Montana; and (4) manganese deposits in Augusta County, Va.

MICHAEL GOLDBERG, engineer, Bureau of Ordnance, Navy Department, Washington, D.C., in recognition of contributions to mathematics.

RONALD BAMFORD, professor, University of Maryland, College Park, Md., in recognition of outstanding contributions in the field of botany, particularly with reference to cytology.

RICHARD STEVENS BURINGTON, associate professor of mathematics, Case School of Applied Science (on leave), consulting mathematician and mathematical physicist, U. S. Navy, Washington, D. C., in recognition of contributions to pure and applied mathematics, in particular to electric circuit theory.

GEORGE TOBIAS FAUST, associate mineralogist, U. S. Geological Survey, Washington, D. C., in recognition of work in mineralogy and petrology.

NONRESIDENT

EDWARD C. RANEY, instructor in zoölogy, Cornell University, Ithaca, N. Y., in recognition of contributions to our knowledge of the fresh-water fishes of eastern North America.

ABRAHAM SINKOV, cryptanalyst, Signal Corps, U. S. Army, in recognition of contributions to algebra, in particular to the theory of finite groups.

ROBERT BIGHAM BRODE, professor of physics, University of California, Berkeley, Calif., in recognition of work on electronic phenomena in gases and metal vapors, and on cosmic rays.

ROBERT S. CAMPBELL, assistant chief, Division of Range Research, U. S. Forest Service,

New Orleans, La., in recognition of contributions in the field of range research, and in particular for pioneering work in the development of range utilization standards.

F. G. BRICKWEDDE, *Secretary*

BOTANICAL SOCIETY

The meetings for 1944 (except the banquet) were held in the Auditorium of the Cosmos Club, President J. R. MAGNESS or Vice-President EGBERT H. WALKER presiding. Attendance ranged from about 60 to 100 persons. Other officers for the year were: GLENN GREATHOUSE, Treasurer; Miss MARY G. VAN METER, Corresponding Secretary; Mrs. ANNIE MAY KARRER, Recording Secretary; F. V. RAND and R. K. BEATTIE, counsellors; L. E. YOCUM, representative to the Washington Academy.

Nine new members were elected during the year: JOHN R. BOWMAN, Lt. HAROLD C. BOLD, JEAN TURPIN, OSCAR R. MATHEWS, Miss JANE ROLLER, FLOYD A. MCCLURE, HERBERT F. BERGMAN, Mrs. HELEN WHITE WILLIAMS, and CURTIS MAY.

Two members died during the year: Lt. Col. GEORGE E. HALLIDAY, formerly assistant biochemist in the U. S. Department of Agriculture, killed in action in Italy on July 25; and LYSTER H. DEWEY, in charge of fiber crop investigations of the U. S. Department of Agriculture from 1890 to 1935, on November 27.

The formal programs were prefaced by book reviews and comments on observations of botanical interest and were followed by a social hour with refreshments. A list of the papers presented is given herewith. Brief résumés of these papers are included in the minutes.

334TH MEETING, JANUARY 4

The botany of the flat-rocks of the Southeast. ROGERS MCVAUGH, Bureau of Plant Industry.

A botanical trip through North Carolina. D. S. CORRELL, Bureau of Plant Industry.

335TH MEETING, FEBRUARY 1

Some current research objectives and field observations on cinchona in Central and South America. W. C. DAVIS, Office of Foreign Agricultural Relations.

Pasture and forage crops and their utilization on tropical American farms. RALPH E. HODGSON, Bureau of Dairy Industry.

336TH MEETING, MARCH 7

Invitation to study of Western Hemisphere bamboos. F. A. MCCLURE, Smithsonian Institution.

The Pan American Highway in Central America and its botanical aspects. ARTHUR BEVAN and W. A. DAYTON, U. S. Forest Service.

337TH MEETING, APRIL 4

Our native orchids. P. L. RICKER, Bureau of Plant Industry.

Developing American Easter lilies to replace stocks formerly received from Japan. S. M. EMSWELLER, Bureau of Plant Industry.

BANQUET MEETING, APRIL 25

The annual banquet was served at All Souls Unitarian Church with 188 persons present, including five honor guests: E. D. MERRILL, JOSEPH F. ROCK, C. R. BALL, H. L. SHANTZ, and H. B. HUMPHREY. The last three were honored in accordance with the Society's custom of so recognizing the retirement of its members from active professional life. The group enjoyed a talk by Liberty Hyde Bailey, author and horticulturalist, formerly of Cornell University, on his botanical experiences of the past half century.

338TH MEETING, JUNE 6

Preservation of plant specimens in as nearly a natural condition as possible. G. R. FESSENDEN, Bureau of Plant Industry.

Strawberry breeding. G. M. DARROW, Bureau of Plant Industry.

339TH MEETING, OCTOBER 3

Two years in China advising on potato improvement. THEODORE DYKSTRA, Bureau of Plant Industry and Division of Cultural Relations, State Department.

340TH MEETING, NOVEMBER 7

Exploring for rotenone in Colombia. F. J. HERMANN, Bureau of Plant Industry and Foreign Economic Administration.

Phloem necrosis disease of elm. CURTIS MAY, Bureau of Plant Industry.

341ST MEETING, DECEMBER 5

Botanist abroad; or A philosophy for the "Good Neighbor." W. A. ARCHER, Office of Foreign Agricultural Relations.

Climatic analogues for plant introduction purposes. MICHAEL NUTTONSON, United Nations Relief and Rehabilitation Administration.

44TH ANNUAL MEETING, DECEMBER 5

After the reports of the Executive Committee and the Treasurer were read, that of the Nominating Committee for officers for 1945 was presented. There being no additional nominations, the Society voted to instruct the Recording Secretary to cast a unanimous ballot for the following nominees: President, AARON G. JOHNSON; Vice-President, FREDERICK V. RAND; Recording Secretary, NEIL W. STUART; Corresponding Secretary, Miss JANICE S. BROWN; Treasurer, ROSS W. DAVIDSON; Counsellors, SAMUEL L. EMSWELLER and ROBERT L. WEINTRAUB; Representative to the Washington Academy, F. P. CULLINAN.

ANNIE MAY KARRER, *Recording Secretary*

Obituary

JOHN FRANKLIN MEYER, retired member of the Washington Academy of Sciences, died on October 30, 1944, after an illness which had confined him to his home for more than four years. Dr. Meyer was born in central Pennsylvania on March 11, 1875. He came of "Pennsylvania Dutch" stock and was a good example of that stable and dependable element of our population.

Meyer graduated from Franklin and Marshall College at the age of 19. For 15 years thereafter he alternated between teaching and further study. He received a master's degree from Franklin and Marshall in 1897, attended Johns Hopkins University for 3 years, and completed his work for the doctorate in 1904 at the University of Pennsylvania. After five years of teaching (1902–1907) at that institution he went to Pennsylvania State College as professor of physics.

The year 1909 brought two notable changes in his life. He married Ella Jane Mather and left academic work to become director of physical research at the Bloomfield, N. J., works of the Westinghouse Lamp Company. The following four years were a period of rapid development in the lamp industry, bringing an almost complete change from carbon to metal filaments, and Dr. Meyer's industrial experience during this transition was of great value in his later work for the Government.

In 1913, Dr. Meyer came to the National Bureau of Standards as one of a group formed to study technical problems arising in the governmental regulation of public-utility services. He compiled the most complete collection of information on state and city regulations regarding electric service, and this was published by the Bureau of Standards in two editions (1916 and 1923) under the title *Standards for electric service*. In 1923 he was put in charge of the Bureau's section on photometry and illumination and was also made assistant chief of the Division of Electricity. He filled those positions until his retirement and was also given many other responsibilities, particularly in committee work. He had previously been assigned to the staff of the Congressional Commission on Reclassification and took an important part in the surveys of governmental and industrial employment which led to the reclassification of the departmental Civil Service in 1924. He became secretary of the Conference of State Public Utilities Commission Engineers in 1929 and held that office until his retirement. He suffered a stroke during one of the sessions of the Conference in May 1940 and was never able to return to full-time duty thereafter. His retirement took effect on January 31, 1941.

Dr. Meyer belonged to many organizations and was an effective worker in them because of his modesty, good judgment, and sincere interest in furthering any good cause. He served the Academy as an editor of the JOURNAL from 1918 to 1921. He was a member of the Philosophical Society of Washington, American Institute of Electrical Engineers, Illuminating Engineering Society, Optical Society of America, the Masonic Order, Acacia fraternity, Phi Gamma Delta, Phi Beta Kappa, Sigma Xi, and the Cosmos Club. Besides his technical activities he maintained a lively interest in religious and social questions and in educational work, being a member of the Advisory Council of Franklin and Marshall College, a trustee of Catawba College, and an officer of the Evangelical and Reformed Church. While holding administrative positions Dr. Meyer never forgot the interests and the feelings of his fellow workers, and any associate whether of high rank or low could be sure of receiving sympathetic consideration of problems brought to him. He will long be remembered as "one who loved his fellow men."

E. C. CRITTENDEN